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THE UNIVERSITY OF ALBERTA

THE SURFICIAL GEOLOGY OF THE COOKING LAKE MORAINE, EAST-CENTRAL ALBERTA, CANADA

by

© Donald Emerson

A THESIS

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DEDICATION

TO MY FOLKS

ABSTRACT

The Cooking Lake moraine of east-central Alberta is comprised of two till units which were deposited during two phases of continental ice sheet disintegration. A radiocarbon date of 52,000 ± 1760 years B.P. on wood taken from above the lower till in the Fort Assiniboine region suggests the older of the two tills to be early Wisconsin in age. A bedrock high, composed of several upper Cretaceous marine facies, forms the nucleus around which break-up of the two ice advances took place.

The two tills of the moraine are differentiated on the basis of colour, structure, and clay mineralogy. Both were deposited from ice sheets which moved into the area from the Shield to the north-east. Other analytical data including texture, lithology (1-2 mm and 10-15 cms fractions), "heavy," "light" and trace element mineralogy and carbonate content cannot be used to differentiate the tills of the area.

The origins of several till depositional landforms which comprise the physiography of the moraine, are shown on the basis of field evidence to incorporate the theories of Gravenor (1955), Stalker (1960) and Clayton (1967). No correlation was found between the density and relief of prairie mounds over the area with bedrock topography.

Radiocarbon dates on shell material taken from

superglacial lacustrine sediments indicate that meltwater was present for approximately 2,000 years after ice of the second continental ice sheet had disappeared. Oxygen isotopes of the shells also show that evaporation was intense throughout the area during late glacial to early postglacial time.

ACKNOWLEDGEMENTS

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The Alberta Research Council kindly made available bedrock topographic and drill hole data of the moraine and National Parks Canada issued sampling and entrance permits for Elk Island National Park.

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CHAPTER 1

INTRODUCTION

The Cooking Lake moraine formed by Laurentide ice sheet advances into central Alberta and is the product of physical processes at work in a stagnating mass of ice as inferred from the landforms present. The moraine is located about 5 miles east of Edmonton and is bounded between latitudes 53° 00' and 53° 46' north and longitudes 112° 40' and 113° 25' west. Its oval shape encompasses an area of approximately 1,100 to 1,200 square miles, with the long axis trending NNE-SSW (Figures 1 and 2).

Laboratory analyses have shown that the moraine is composed of two till units and that ice moved into this area of central Alberta from the north-east on two occasions. Upon encountering and enveloping the upper Cretaceous bedrock high which comprises the core of the moraine, the ice sheet began to disintegrate in situ leaving behind a hummocky topography typical of stagnating glacial environments today.

The exact times of ice advance into the area are uncertain and it is also difficult to deduce whether the two till units were deposited during two closely spaced but separate advances or two quite distinct advances.

OBJECTIVES OF THE STUDY

The objectives of the study were as follows:

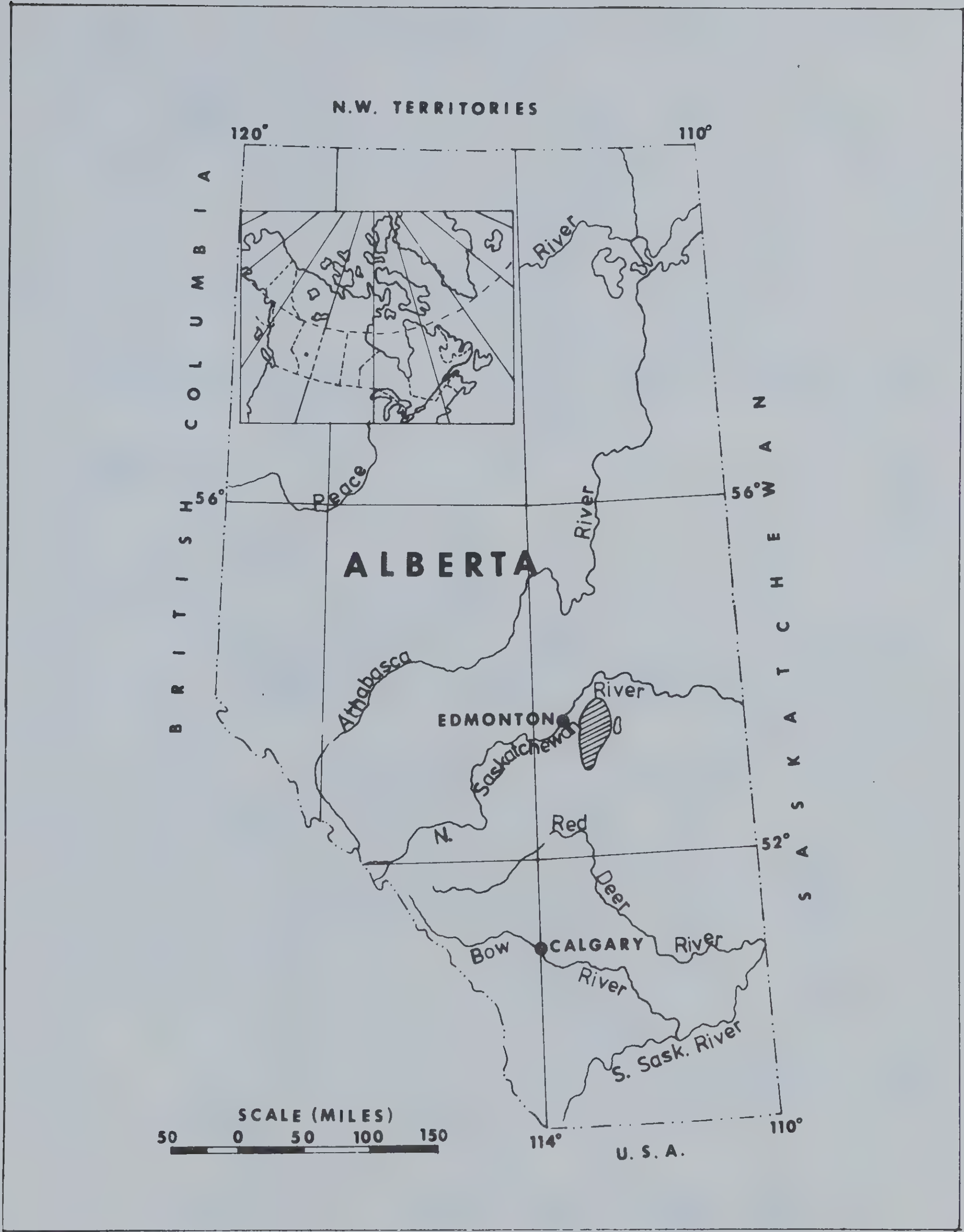
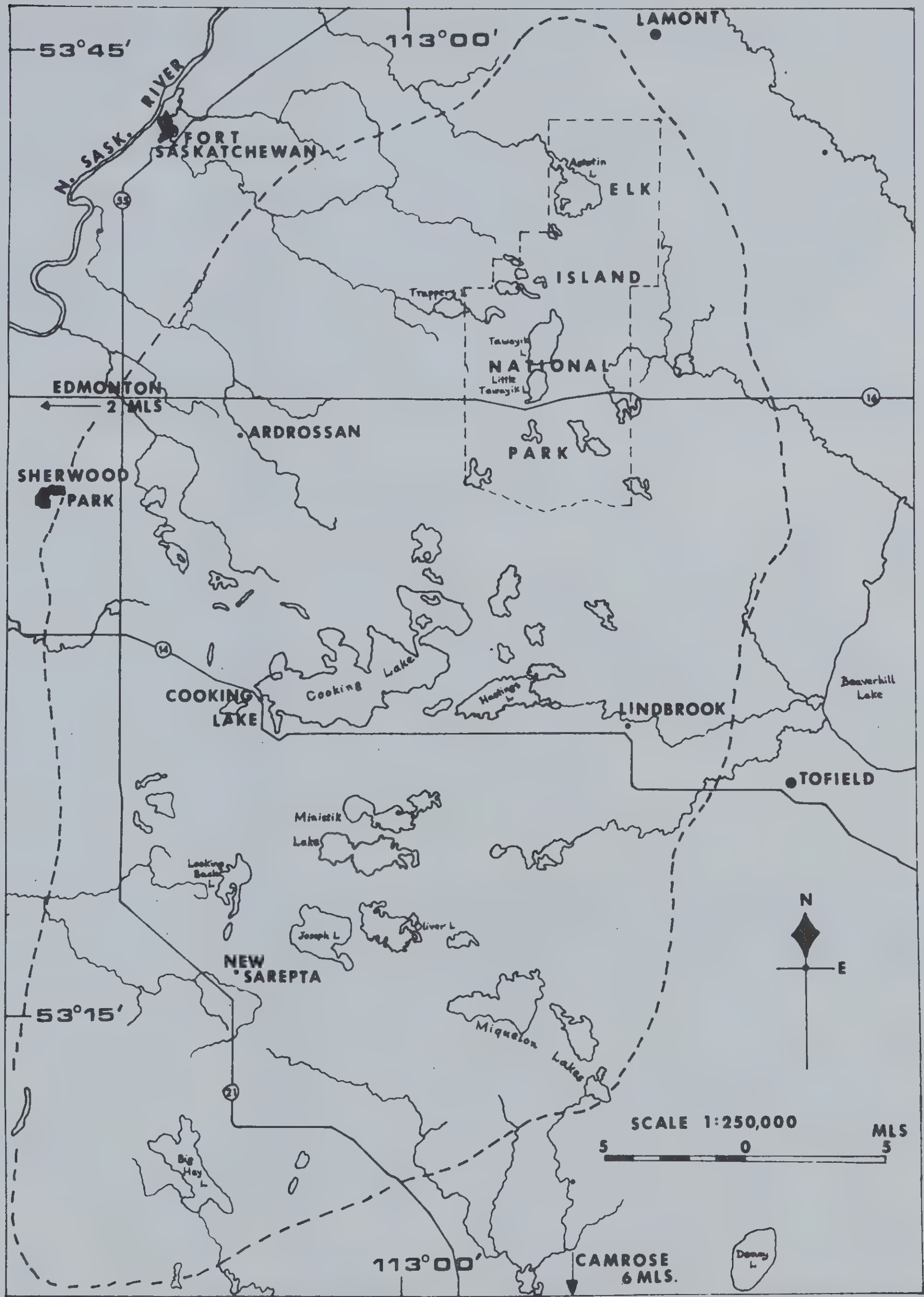


Figure 1. Location of the Cooking Lake moraine (shaded area).



Fiqure 2. Map showing the outline of the moraine.

1. To map the parent materials and landforms of the Cooking Lake moraine.

2. To distinguish the number of tills in the area.

3. To critically evaluate the existing theories pertaining to the origin and formation of ice disintegration landforms and to deduce a process which satisfactorily accounts for the origins of such features in the moraine.

4. To construct the geological history of the moraine.

METHODS OF INVESTIGATION

Preliminary Study

Prior to the field season of 1975, aerial photographic interpretation was made of the moraine to distinguish the types of materials and landforms present and to delineate the palaeo- and recent drainage systems.

Field Work

Mapping of the Cooking Lake moraine commenced in June 1975 following preliminary field work carried out during the Fall of 1974 and the Spring of 1975.

In order to traverse the moraine as completely as possible, it was found that the existing road network provided a satisfactory grid over and from which to map the surficial geology. Motorcycle and bicycle were used as means of transport, although points of interest off the roads and remote spots such as in Elk Island Park, necessitated coverage by foot.

Sections exposed beside roads provided the best

opportunities for obtaining till, superglacial lacustrine and other types of samples. When sampling, a vertical interval of approximately one foot was used and where there were not road sections, it was necessary to obtain samples by shallow digging. Deep, subsurface till samples around Hastings Lake were obtained by commercial auger drilling, which also provided information pertaining to the elevation of the till-bedrock interface in this region of the moraine.

Laboratory Analyses

Following the completion of field work, samples were analyzed in the lab. The details, results and interpretations of these analyses are described in Chapter 3.

PREVIOUS INVESTIGATIONS

The first detailed map of the surficial geology in the area was by L. Bayrock and G. Hughes (1962). This map, which is centred on Edmonton, incorporates the western half of the moraine. The eastern half has, until the present study, remained undocumented.

V. Carlson (1967) published a bedrock topographic map of the area mapped by Bayrock and Hughes.

J. A. Westgate (1968, 1969 and 1976) has described the jointing patterns, linear sole structures and till fabrics of the Edmonton tills. S. Pawluk and L. Bayrock (1969) described several characteristics and physical properties of Albertan tills.

The sequence of occurrence of glacial lakes in north-central Alberta, including glacial Lake Edmonton has been documented by D. St. Onge (1972).

F. W. Schwartz (unpublished) has determined the patterns and chemical properties of groundwater flow around Hastings Lake.

CHAPTER 2

THE PREGLACIAL PHYSIOGRAPHY OF THE AREA

Preglacial Topography

Prior to glaciation, the area now covered by the moraine was an upland of upper Cretaceous bedrock. Three formations of marine facies comprise the geology of this upland and each is described below in order of decreasing age. The gentle, regional dip of each formation is to the south-west, the overall geology being shown in Figure 3.

a) The Belly River Formation is composed predominantly of sandstone, siltstone and mudstone.

b) The Bearpaw Formation is composed of silty-shale and clay rich sandstone and overlies the Belly River Formation.

c) The Edmonton Formation directly underlies the bulk of the moraine and extends westwards to the North Saskatchewan River where it crops out along the valley sides. The facies is characterized by sandstone, mudstone, shale, ironstone and coal beds. It overlies the other two formations and forms a distinct scarp which trends approximately in a NW-SE line between Lamont and the north-western shore of Beaverhill Lake. Along this scarp there is also a distinct break between the hummocky stagnation topography of the moraine on top and the low rolling relief of the ground moraine on the adjoining plain.

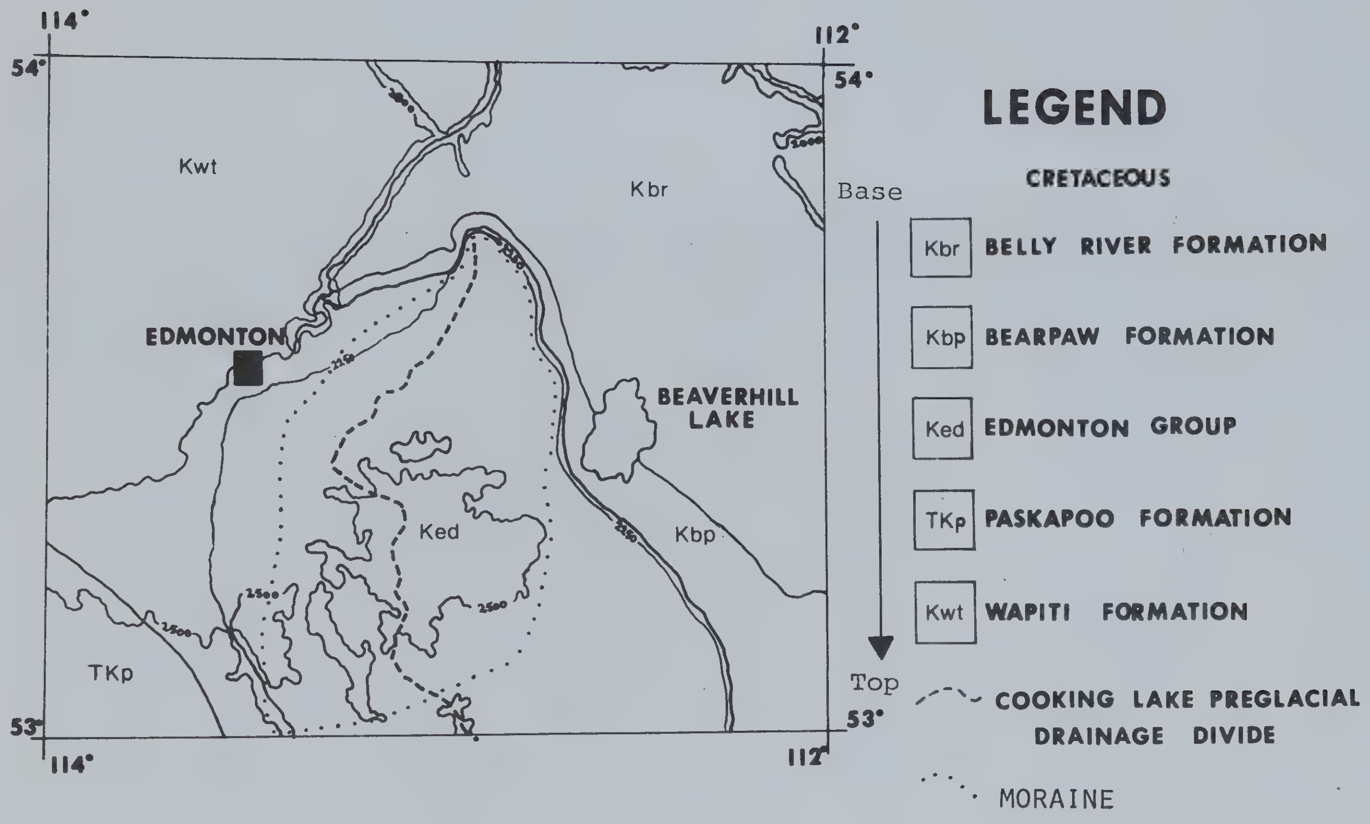


Figure 3. Geology of the bedrock underlying the moraine.

Most of what is known about the preglacial topography and physiography of the western half of the area is provided by V. Carlson (1967).

A distinct central axial ridge marks the preglacial drainage divide, the maximum elevation of which is 2,550 feet just west of the present western shoreline of Joseph Lake. From here the topography descends towards the north and south (Figure 3).

Several exposures of bedrock are present in the area just north of Cooking Lake, the largest being shown in Plate 1. Figure 4 locates all the known bedrock outcrops.

Some debate has arisen as to whether the exposures constitute an in situ bedrock high of upper Cretaceous Edmonton Formation facies or whether they form part of an extremely large erratic rafted in from the Grand Rapids Formation of the Fort McMurray area. Microfaunal analyses (Bayrock and Hughes, 1962) support the latter, although together the exposures outline an area of approximately eight square miles.

Preglacial Drainage

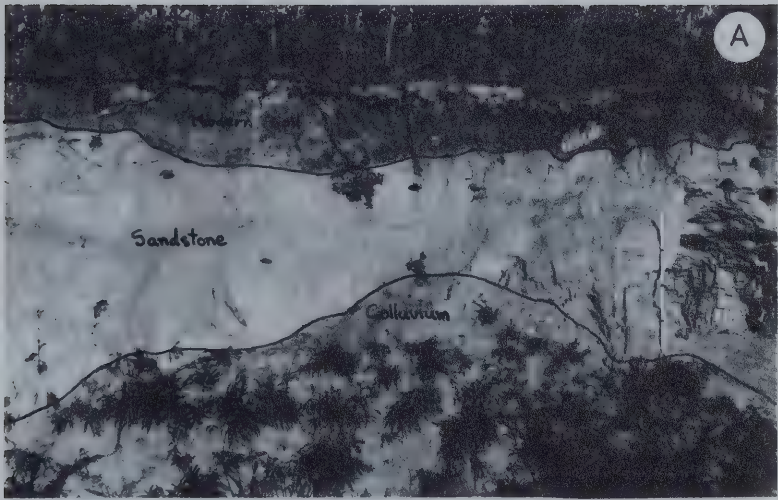
The preglacial drainage system was a direct expression of the bedrock topography (Carlson, 1967).

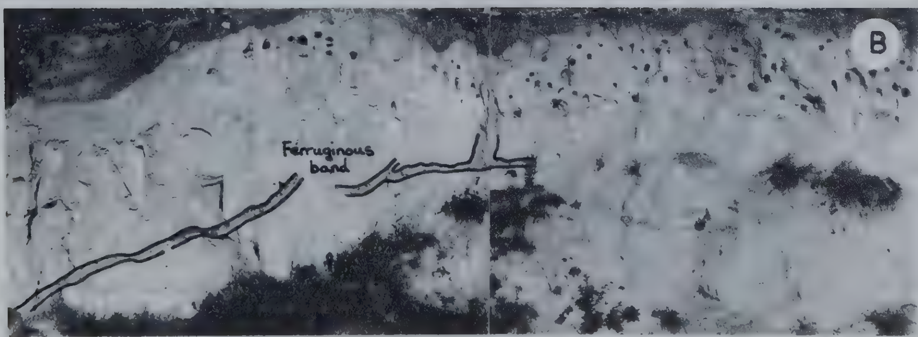
To the west of the Cooking Lake divide, the surface water drained in a west to north-west direction into the preglacial North Saskatchewan River valley which, although not occupying the same channel as it does today, did flow

Plate 1

A and B. Bedrock exposures at section location 16175.
(The scale pole is in one foot divisions.)

PLATE 1





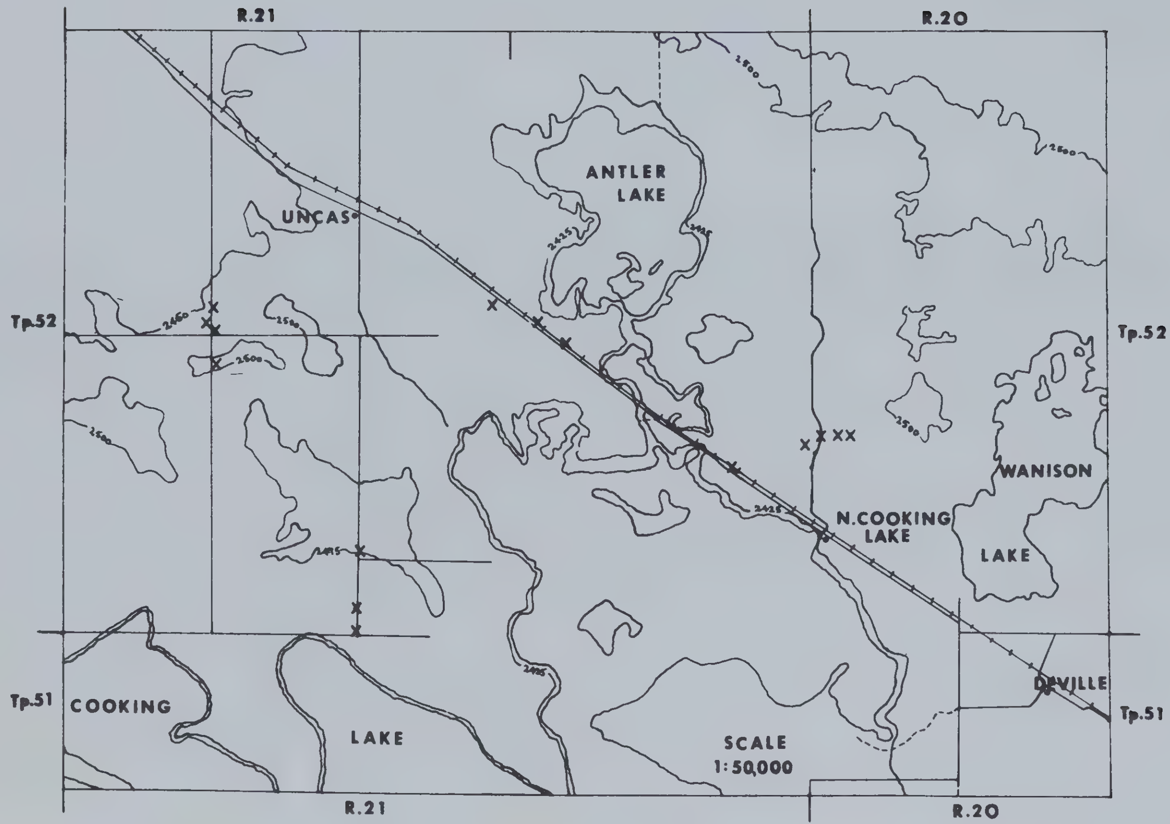


Figure 4. Bedrock exposures in the moraine (marked by X).

through the same general area.

East of the divide, recent drilling in the area around Cooking and Hastings lakes has revealed the presence of a 200 foot deep trough, the axis of which trends approximately west to east. This channel carried the bulk of the surface drainage of the upland eastwards, connecting with the preglacial Athabasca River channel to the north-east. Figure 5 shows the extent and dimensions of this channel. Two shallower channels, which pass under the areas now marked by Ministik Lake and Joseph and Oliver lakes, also flowed to the north-east, after coalescing close to the town of Tofield.

At the present time, data for the bedrock topography of the north-eastern quadrant of the area is unavailable.

THE SYNGLACIAL PHYSIOGRAPHY OF THE AREA

Every region in the world today where glaciers and ice masses are stagnating presents first hand evidence to support the premise that a glacial stagnation topography is a direct function of the mode of deposition of the material which was carried in the moving ice.

The physiography of the Cooking Lake moraine has changed little since its formation during glacial time. This is primarily due to the poor development of surface drainage. Therefore, the present physiography of the moraine is very similar to that which characterized the area during the latter stages of glaciation.

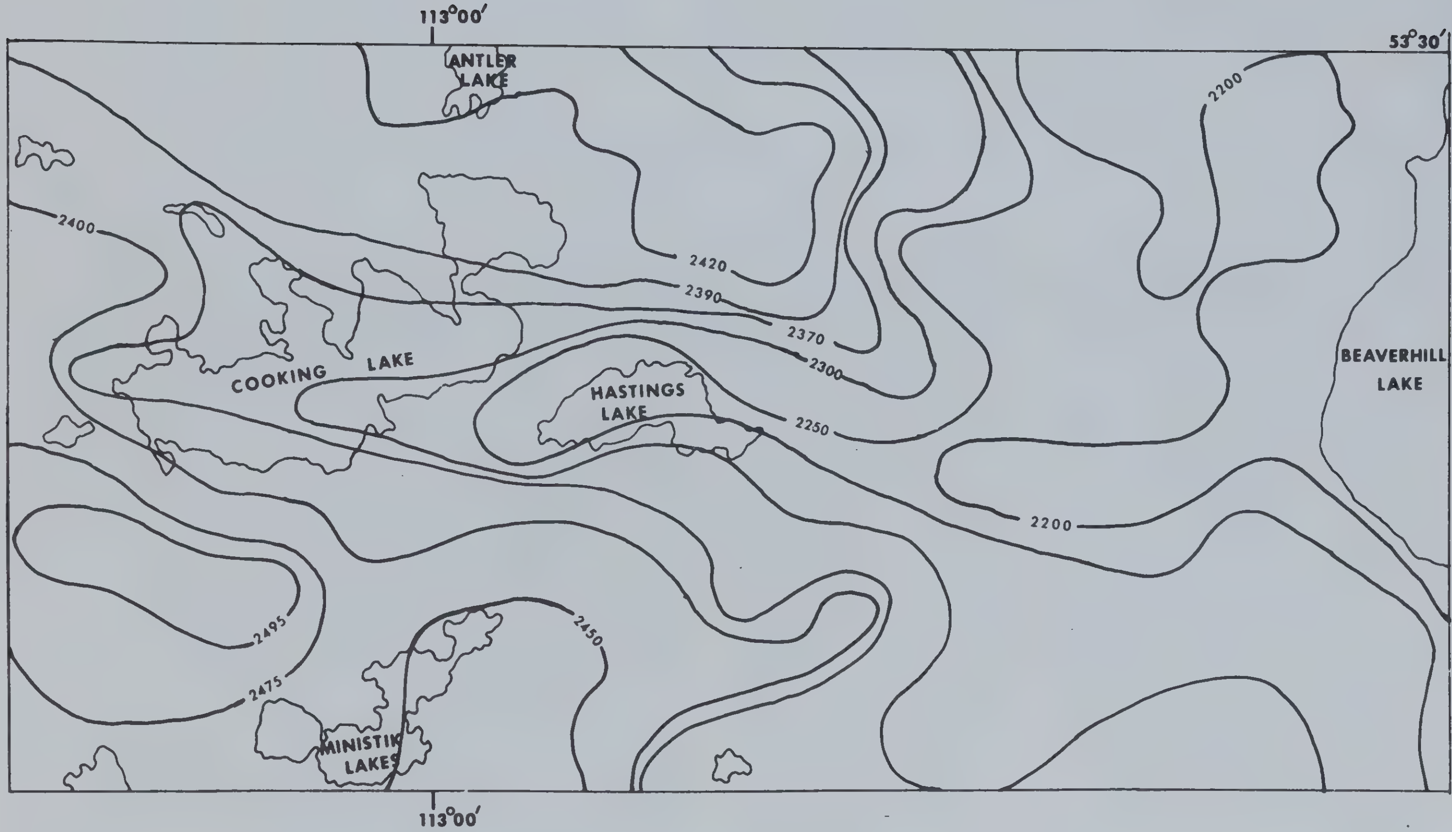


Figure 5. The Cooking-Hastings Lake preglacial drainage channel.

Synglacial Drainage

Map 2 presents the synglacial surface drainage of the Cooking Lake area. Landforms of glacial meltwater origin, such as stream trenches and deltas, strongly suggest a greater supply of surface water during the period of ice stagnation than at present. As a result, lake levels were more extensive than today and the following two major lake bodies existed.

1. The Cooking-Hastings Lake system, and
2. The Joseph-Oliver-Ministik-Miquelon system.

The evidence is based upon:

1. the relief and shape of the present land surface, and
2. the extent of impounded lacustrine deposits beyond present day lake margins.

However, studies by F. W. Schwartz (personal communication, 1976) show that Joseph Lake today is different from Oliver, Ministik and Miquelon lakes, on the basis of its water chemistry. The proposed explanation of this anomaly is that the water chemistry of these lakes was the same during glacial time and only changed when the original lake body broke up as a result of postglacial evaporation.

Synglacial drainage on the western half of the moraine is difficult to determine. From the evidence of landforms such as stream trenches, drainage was towards the south via Big Hay Lake and Bittern Lake with a collecting area around the town of New Sarepta where a reticulate system of

stream channels has developed.

Hastings Lake drains eastward into Beaverhill Lake at the present time and together with the fact that the preglacial drainage also flowed east in this area along a prominent bedrock channel, it is inferred that the synglacial drainage of the area followed a similar course.

In the northern half of the moraine, drainage water collected in the area of the southern half of Elk Island National Park. Small meltwater stream trenches coalesced and flowed north to join up with a major trunk where the Tawayik lakes are located today. The system then joined up with Oster Lake and flowed towards the north-west, where it drained into glacial Lake Edmonton via a large delta. Today this delta region is marked by an extensive cover of fluvioglacial sands and gravels one mile due west of the National Park western gate, and covering an area of approximately four square miles. It also marked the outlet for the smaller Astotin Lake system (see Map 2). The sands and gravels of the delta gradually thin out as the relief decreases towards the town of Josephburg to the north-west. Plate 2A shows a cross section of the delta and Plate 11B shows a close up view of the uppermost horizons of the section, the dark horizon representing the major forest fire of 1897. Figure 6 shows the pebble fabric of the delta.

Most meltwater in the northern half of the moraine flowed to the north-west. However some water drained east

Plate 2

A. Cross-section of the delta north-west of Elk Island National Park. (Scale pole in one foot divisions.)

B. View of typical ground moraine.

PLATE 2

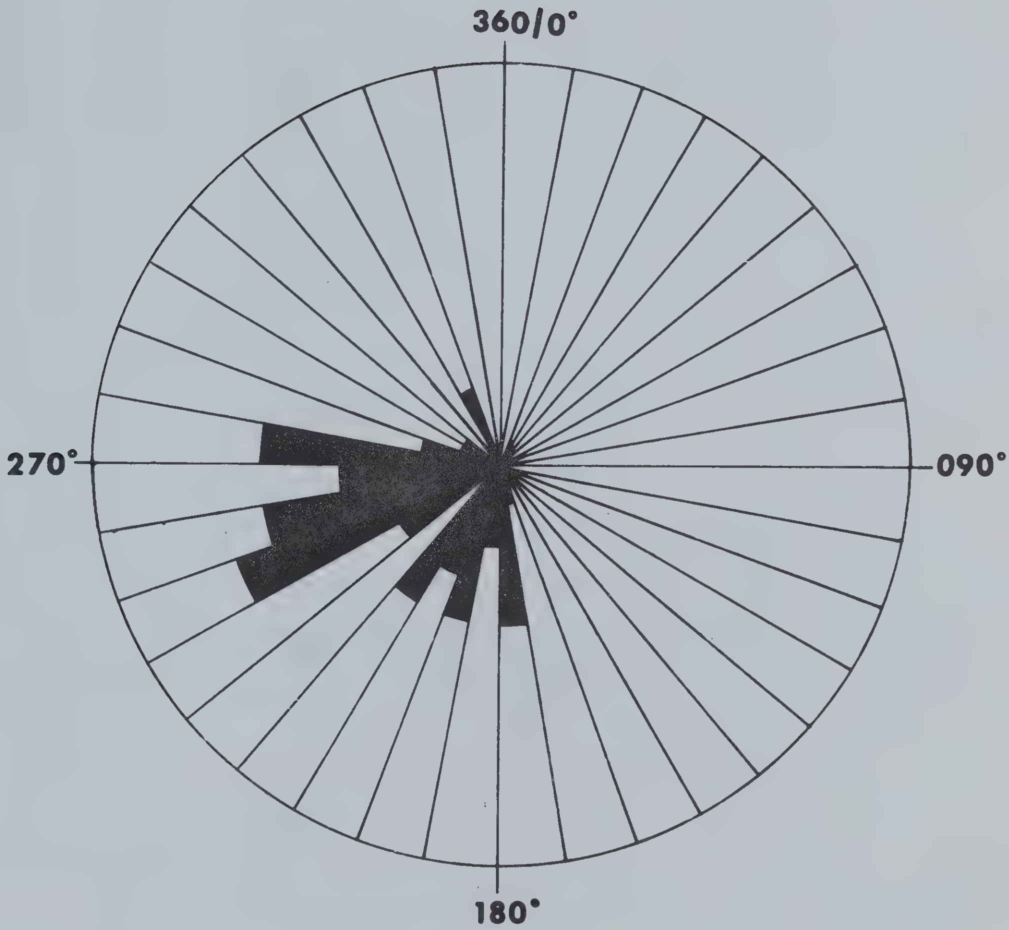


Figure 6. Pebble fabric in the delta, north-west of Elk Island National Park.

over the prominent scarp formed by the Edmonton Formation. At frequent intervals along this scarp, fluvioglacial fans of sands and gravels occur, the fabrics of which are all oriented in a SW-NE direction (Figure 7). The fans can be traced for some distance out onto the eastern plain of ground moraine where they thin and gradually fade out. Synglacial drainage was still active even when ice had largely disappeared from on top of the moraine and had retreated some distance to the north-east. Refer to Figure 8 and Map 1.

In addition to the above, minor systems flowed in all directions off the moraine. Evidence for this is found in the fluvioglacial outwash approximately one mile west of Sherwood Park and just north of Highway 16, where an extensive area is covered by fine sand and silt. Runoff sands and gravels are also found scattered over the eastern slopes of the moraine, especially in the vicinity just west of the town of Tofield.

Synglacial Landforms

The Cooking Lake moraine possesses excellent examples of many types of synglacial landforms. Many of these, although not immediately discernable from ground level are distinctive when seen on aerial photographs. Each type will be discussed under the headings of depositional, erosional and melt-out landforms.

Depositional Landforms

Ground moraine. All till of relief 0 to 10 feet

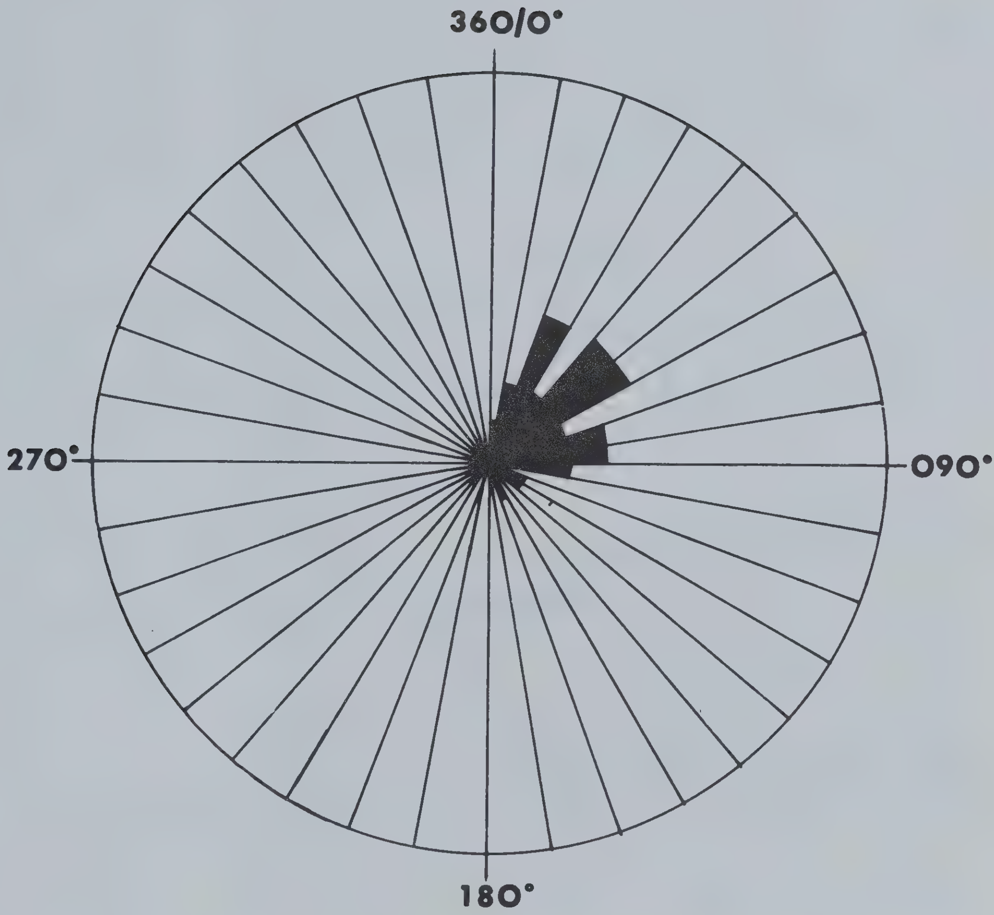


Figure 7. Pebble fabric in an outwash fan along the scarp to the north-east.

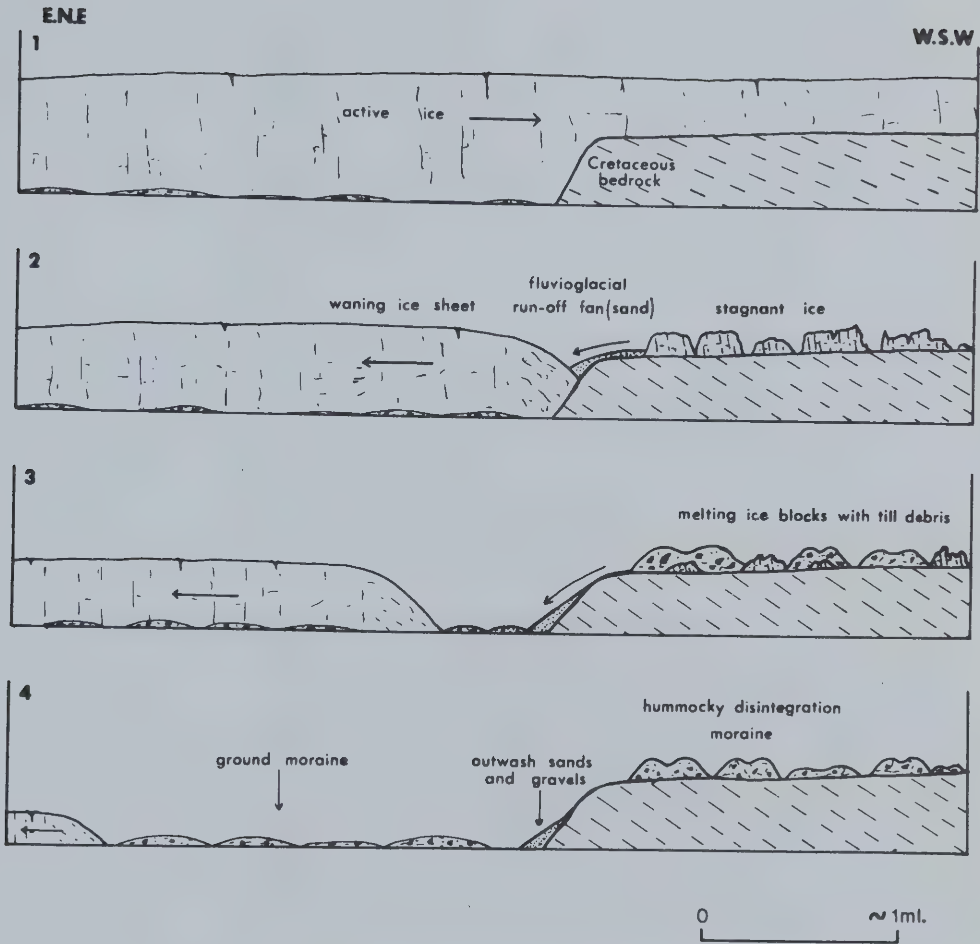


Figure 8. Sequence of diagrams explaining the formation of outwash fans along the north-east scarp of the moraine.

between the top of a hummock and the floor of the adjacent depression and with inter-hummock distances greater than 40 yards was mapped as ground moraine. Ground moraine was deposited at the base of a slowly moving continental ice sheet. Plate 2B shows typical ground moraine topography.

Hummocky disintegration moraine. Often referred to in the literature as stagnation or "knob and kettle" topography, this type of landform in itself is a combination of many different landforms which developed as functions of the physical properties inherent to a disintegrating ice sheet. As a landform unit, it was mapped as three divisions based on relief characteristics and spacing distance between adjacent hummocks. These divisions are:

1. Low hummocky disintegration moraine with vertical relief variation between 0 and 10 feet and lateral distance between adjacent hummock tops being less than 40 yards to distinguish it from ground moraine (Plate 3A).

2. Medium hummocky disintegration moraine with relief variation of 10 to 30 feet and lateral distance less than 40 yards (Plate 3B).

3. High hummocky disintegration moraine with relief variation of 30 feet and over, with lateral spacing also less than 40 yards.

Appendix 6 shows the distribution of these three variations of moraine over the central portion of the mapped area.

Synglacial lacustrine deposits. Synglacial lacustrine

Plate 3

A. View of typical low relief hummocky disintegration moraine.

B. View of typical medium relief hummocky disintegration moraine.

PLATE 3

A

B

deposits over the Cooking Lake moraine were, on the basis of field evidence, inferred to be largely of superglacial and glacially impounded origin.

Superglacial lacustrine deposits are found within the central depressions of prairie mounds, draping the flanks of prairie mounds and ridges and also on the floors of inter-hummock depressions. Plates 4A and B show a typical stratigraphy of material in a prairie mound depression.

Impounded lacustrine deposits lie, usually as flat expanses, beyond the margins of existing major lakes in the moraine. During glacial time these lakes were ice impounded and of greater extent than today.

Proglacial lacustrine deposits are present in the Edmonton area as a flat plain which is at a lower elevation than the moraine. This plain represents the former floor of proglacial Lake Edmonton.

Map 1 shows the distribution of these deposits.

<u>Fluvioglacial outwash features</u>. Sands and gravels constitute the basic surface material of synglacial drainage networks over the moraine. Outwash such as that of the delta just north-west of Elk Island National Park is found around many lakes in the area such as along the northern shores of Cooking and Hastings lakes (see Map 1). The sands and gravels adopt the forms of distinct elongate ridges or mounds. Vertical sections exhibit excellent cross bedding and very distinct fabrics which indicate the palaeocurrent

Plate 4

A. Superglacial sediments overlying till and infilling the central depression of a prairie mound at section location 11575. (Scale pole in one foot divisions.)

B. Close-up of the sediments in section 11575.

PLATE 4

directions of the flowing water depositing the material. These directions are shown on Map 2 for each locality at which fabrics were measured. Plate 5A shows well developed cross bedding and current direction in a fluvioglacial outwash section on the north shore of Cooking Lake at location 53° 26' 40" N and 113° 02' 03" W.

Kames. Kames are rare over the moraine and where present, can not be recognized with any degree of certainty. The best example occurs just north of the soap holes in the north-eastern sector of Elk Island National Park at 52° 37' N and 112° 49' W. It forms a large mound approximately 50 feet in height with a basal diameter of 50 to 100 yards and is composed of sands and gravels. A kame field approximately one square mile in area is situated east of the National Park boundary at 53° 37' N and 112° 45' W. Both landforms are indicated on Map 1.

Eskers. One landform exhibiting esker-like characteristics occurs about three miles north-west of Tofield at 53° 24' N and 112° 43' 30" W. It is approximately 200 yards in length, 50 to 100 yards in width and 8 to 10 feet in height. Composed of poorly sorted, stratified sands and gravels, the feature is sinuous in shape.

Linear disintegration ridges. Till ridges, discernable mainly from aerial photographs, occur frequently over the moraine. However only rarely do they adopt a uniform

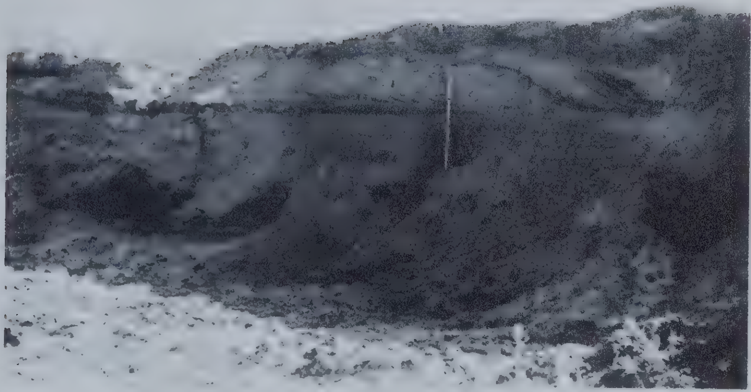
Plate 5

A. Section through outwash sands and gravels on the north shore of Cooking Lake at location 53° 26' 40" N and 113° 02' 03" W. (Scale pole in one foot divisions.)

B. View of a typical stream trench looking east at location 53° 28' 45" N and 113° 10' 00" W.

PLATE 5

A



B

configuration in terms of spacing and shape. Ridges measured in the field commonly show the following characteristics:

a) Ridges may range up to 20 feet and over in height.

b) They commonly meander for distances of up to one mile or more.

c) In many places, ridges intersect at acute angles.

<u>Prairie mounds</u>. Of all the landforms related to ice disintegration in the Cooking Lake moraine, prairie mounds occur most frequently. They are sometimes referred to as "prairie doughnuts," mainly because of their appearance when viewed from above. Typical mounds are circular with a basal diameter of approximately 300 feet and have a central depression, the rims of which are in the order of 15 feet above the surrounding land surface. The depression frequently, but not always, is characterized by the presence of thin lacustrine deposits, the original lakes having long dried up.

In addition to prairie mounds which exhibit the above characteristics, the Cooking Lake moraine has mounds which are not completely circular. Many are breached at some part on their circumferences and in extreme cases, broad, arcuate ridges occur. It is questionable whether the arcuate ridges are in fact true prairie mounds at all. Uncertainty such as this is also true in areas where mounds occasionally exhibit patterns of apparent intergrowth when viewed from above.

The typical prairie mound, as measured in the field, shows the following mean dimensions with variation shown in

brackets. Eleven mounds were measured.

Basal diameter = 348 feet (105 feet - 510 feet)

Maximum height of rim = 18 feet (7 - 36 feet)

Depth of central depression = 4 feet ($1\frac{1}{3}$ - 10 feet)

Outer slope gradient ≃ 38° (20° - 55°)

Inner slope gradient ≃ 25° (20° - 30°)

Figure 9 shows three prairie mound cross sections which were measured in the field and Figure 10 is a computer print-out which displays the density distribution of prairie mounds (i.e., number of mounds per square mile) over the central part of the moraine. Data for the north-eastern sector and the peripheries of the moraine were not collected in the field.

The lowest prairie mound densities are found in the central part of the moraine and along an area extending towards the north-east. The peripheries are, in general, noted for higher prairie mound densities.

No correlation exists between:

1. Prairie mound density and the elevation of the underlying bedrock, or,

2. surficial relief and the bedrock elevation,

for the area outlined in Figure 10.

Contingency coefficients of 0.03 and 0.09 were calculated for the correlation of these two sets of data respectively. The three sets of data used are presented in Appendices 5, 6 and 7.

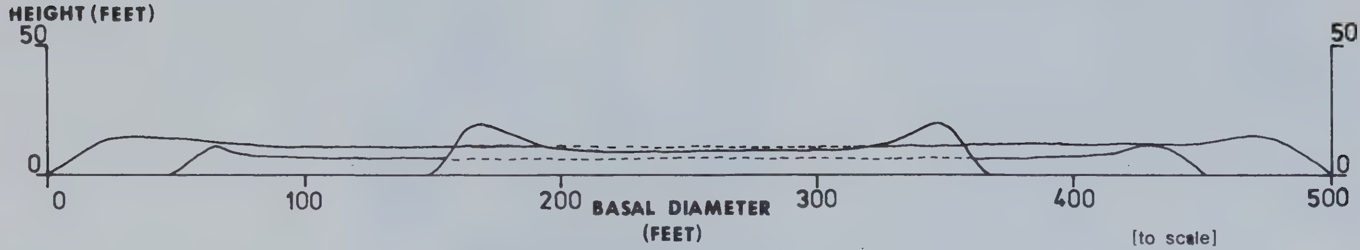


Figure 9. Cross-sections of 3 typical prairie mounds.

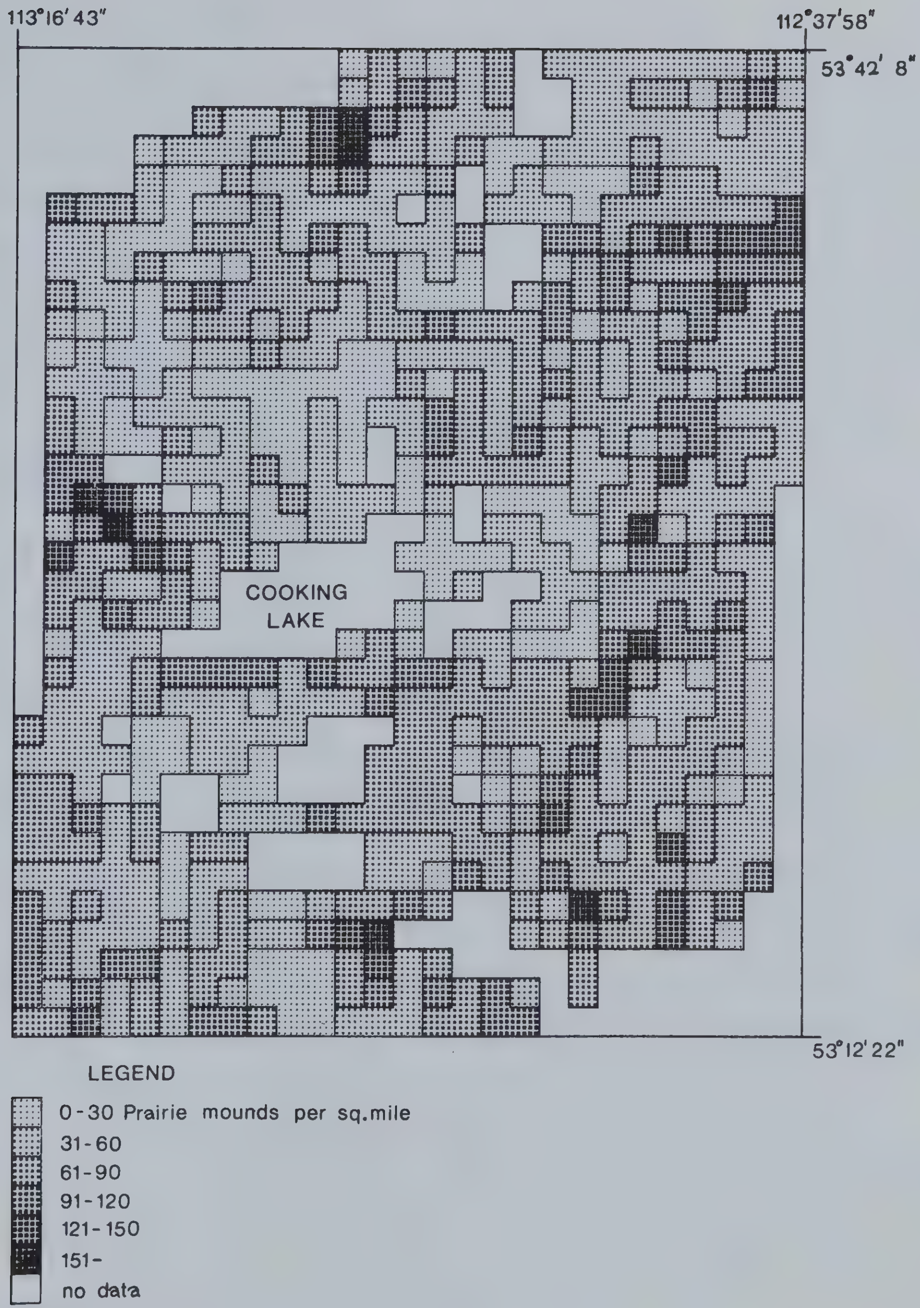


Figure 10. Prairie mound density over the central portion of the moraine.

Erosional Landforms

Stream trenches. Stream trenches are prominent landforms when viewed at ground level or from above. They mark the positions of former meltwater drainage channels which were active at the time of ice disintegration and were thus likely to have been ice contact. Map 2 shows the locations of all major stream trenches over the moraine.

Today these landforms exhibit the following topographic characteristics:

1. Flat bottoms with parallel walls.
2. Sides up to 30 feet in height above the trench floor, with gradients of approximately 45°.
3. Widths in the order of 360 to 400 feet.
4. Varying lengths as a result of the trenches being blocked off and partially buried through till slumpage.

The most prominent trench networks are found in the Cooking Lake and New Sarepta areas. The former drained the land along the northern margins of Cooking Lake and the latter drained the area around New Sarepta. Another drained the Elk Island National Park area to the north-west.

Plate 5B is a view of the main Cooking Lake channel looking east from the road at 53° 28' 45" N and 113° 10' 00" W and Plate 6A is a view looking south-south-west along the channel flowing out from Looking Back Lake at 53° 17' 30" N and 113° 8' 50" W.

In most of the main trenches, remnant lakes are still

Plate 6

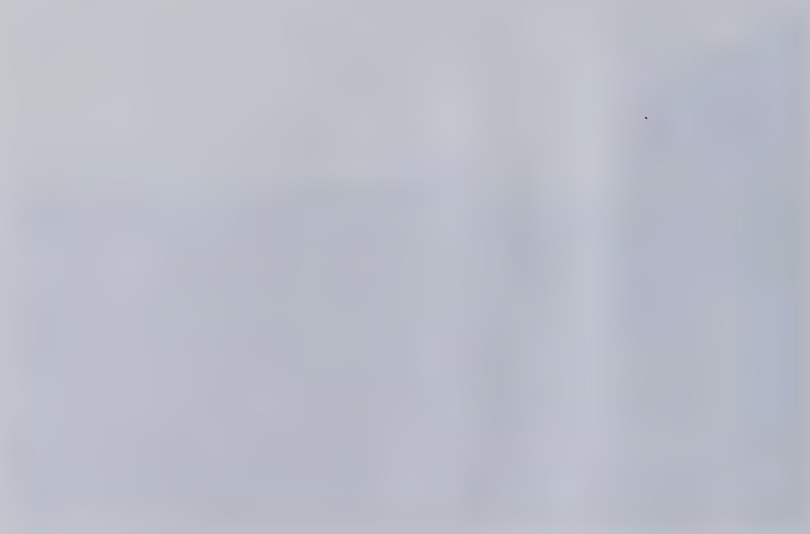
A. View of a stream trench looking SSW at location 53° 17' 30" N and 113° 8' 50" W.

B. View of a typical kettle.

PLATE 6

A

B



in existence. Half Moon Lake, for example, lies within the main Cooking Lake network.

Spillways. The south-west boundary of the moraine is marked by the Gwynne outlet spillway channel through which glacial Lake Edmonton drained to the south.

Melt-out Landforms

This category of landforms encompasses those features formed by the direct melting out of ice blocks either on or below the surface of the ground.

Kettles. Commonly referred to as sloughs, these features are small lakes which partially fill inter-hummock depressions and which formed as a result of the melting out of ice blocks left sitting on the surface during the last stages of ice stagnation.

Plates 6B and 7 all show typical kettles at various localities over the moraine and from them the general dimensions of these features can be gauged. Typical diameters are in the order of 20 to 30 yards and depths vary from less than 5 feet to greater than 19 feet.

Plate 7

A. View of a typical kettle.

B. View of a typical bottomland environment.

PLATE 7

A

B

CHAPTER 3

THE TILL OF THE COOKING LAKE MORAINE

INTRODUCTION

Several standard analyses run on samples of till from the moraine show that it is possible to distinguish more than one till unit. Most results showed that the till of the moraine is homogeneous but several criteria suggest that there are two till units present--a lower and an upper unit. These criteria are described below.

THE SAMPLE LOCATIONS

Figure 11 shows the sampling locations over the moraine. Subsurface material from locations 175, 475 and 675 was obtained by side wall sampling. The mean number of samples taken from each section locality was four but in sections where till is particularly thick, up to eight samples were taken.

CRITERIA WHICH DISTINGUISH TWO UNITS IN THE MORAINE

The following criteria are used to demonstrate that there are two separate till units that represent deposition from two separate ice sheet stagnations in this area of east-central Alberta.

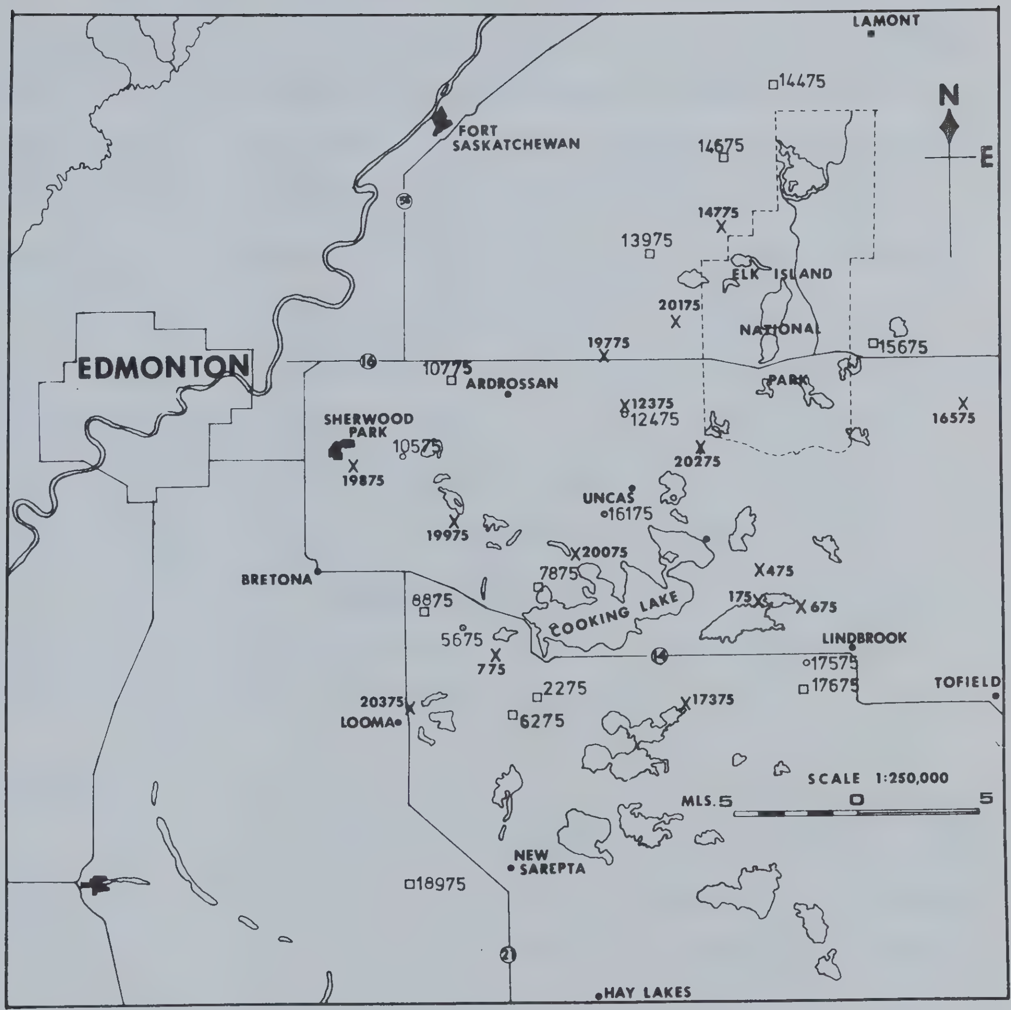


Figure 11. Map showing the locations of sampling sites.

Colour

Two distinct units can be observed in many till sections within the Cooking Lake moraine on the basis of colour. There is a very distinct break between a lower, darker till and an upper, lighter coloured till. This contrast can not be a function of weathering or a fluctuating water table since the interface is not parallel with the ground surface but cuts across sections horizontally. The two units are distinguished on the basis of their chroma and value notations while the general notation of 2.5 Y is the same for both using the Munsell colour scheme. Colour values for both lower and upper tills are presented in Appendix 1.

Colour shows emphatically that two distinct units of till comprise the Cooking Lake moraine, a factor which is further supported by structural criteria.

Structure

The two till units of the moraine which can be separated on their colour, can also be distinguished on the basis of their structure. The upper till unit is characterized by a well developed columnar jointing system which contrasts markedly with the smaller, more compact blocky jointing in the lower till. Where joints are well preserved in the upper unit, two orthogonal sets were measured with the following dimensions:

Mean strikes . . . . 106.5° and 190°

Mean dips . . . . 85.5° and 85° W

Joint set spacing . . . . . 2" 2"

Joints in the lower till were not measured. Plate 11A shows the structural differences between the lower and upper till unit in the area. The contrast in the jointing is sharply defined and coincides with the colour boundary between the two units.

Clay Mineralogy

In addition to the colour and structural contrasts between the two till units, clay mineralogy is also concluded to be an important distinguishing criteria.

Thirty-nine till samples of < 230 mesh grade were prepared by heating and glycolating and analyzed using x-ray diffraction. The data are quantitative and presented in Appendix 1.

Four clay minerals, namely montmorillonite, illite, kaolinite and chlorite were detected and analyzed. Chlorite occurs only in traces and kaolinite comprises a fairly constant 15 to 20% in all samples. Small amounts of sodium chloride, dolomite and calcite were detected in some samples. The clay mineralogy of the tills is shown in Figure 12.

The two clay minerals of importance in characterizing the two till units are montmorillonite and illite. The illite content in both the upper and lower unit is 40% to 75% and the montmorillonite is 10% to 50%.

It is unusual in nature to find illite in greater concentration than montmorillonite except where diagenetic

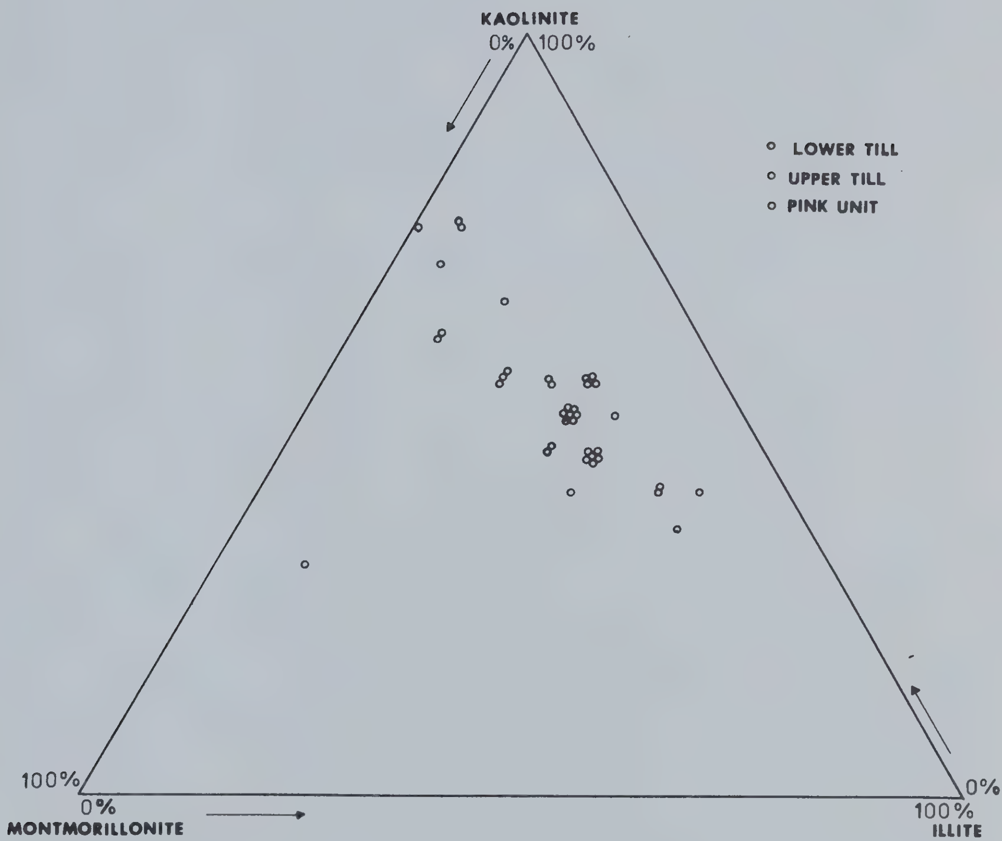


Figure 12. Diagram showing the clay mineralogy of

of selected till and pink unit samples.

processes have occurred to transform the montmorillonite into illite. Such a reaction occurs quickly under aqueous conditions in which appreciable concentrations of potassium and magnesium act as catalysts. An ablating ice environment provides the ideal environment for this. It is interesting to note that both the lower and upper tills in the area surrounding the Cooking Lake moraine (both being basal) have high montmorillonite (up to 70%) and low illite (as low as 10%) contents. The latter data reflect the clay mineralogy of the bedrock over which the material was transported at the base of a moving ice sheet prior to deposition.

The upper and lower tills of the moraine cannot be differentiated on the evidence of clay mineralogy but when compared to the basal tills of the surrounding regions to which the moraine tills are direct corollaries, there is an appreciable difference, i.e., the montmorillonite content of the lower till in the area surrounding the moraine is 10% to 25% higher than the montmorillonite content of the respective upper till.

THE ORIGIN OF THE TILL UNITS

Topographic expression and the lack of any distinct fabric indicate that the upper unit is mainly ablation till. The dominant landforms are prairie mounds and till ridges which formed from a stationary and stagnating ice mass.

An overall, uniform fabric does not exist in the

lower till unit either, and suggests that this unit is also mainly ablation till, although its topography has not been preserved due to the advance of the ice sheet which deposited the upper unit.

OTHER ANALYTICAL PROCEDURES

The following criteria did not prove useful in distinguishing the two till units of the moraine. However, the information gained can be used to describe and characterize the units.

Texture

Textural data for the till samples processed are presented in Appendix 1. The upper till unit has approximately a 1% mean higher sand content and a 1.25% mean lower clay content than the lower unit. However, these textural differences are not considered significant enough to define the tills as separate entities.

Figure 13 shows the positions of upper and lower unit samples on a sand-silt-clay textural triangle.

Lithology

Two size fractions were examined to aid in characterizing the lithology of the upper and lower tills. These were the:

a) 1.00 mm. - 2.00 mm. fraction, and

b) 10 cms. - 15 cms. fraction.

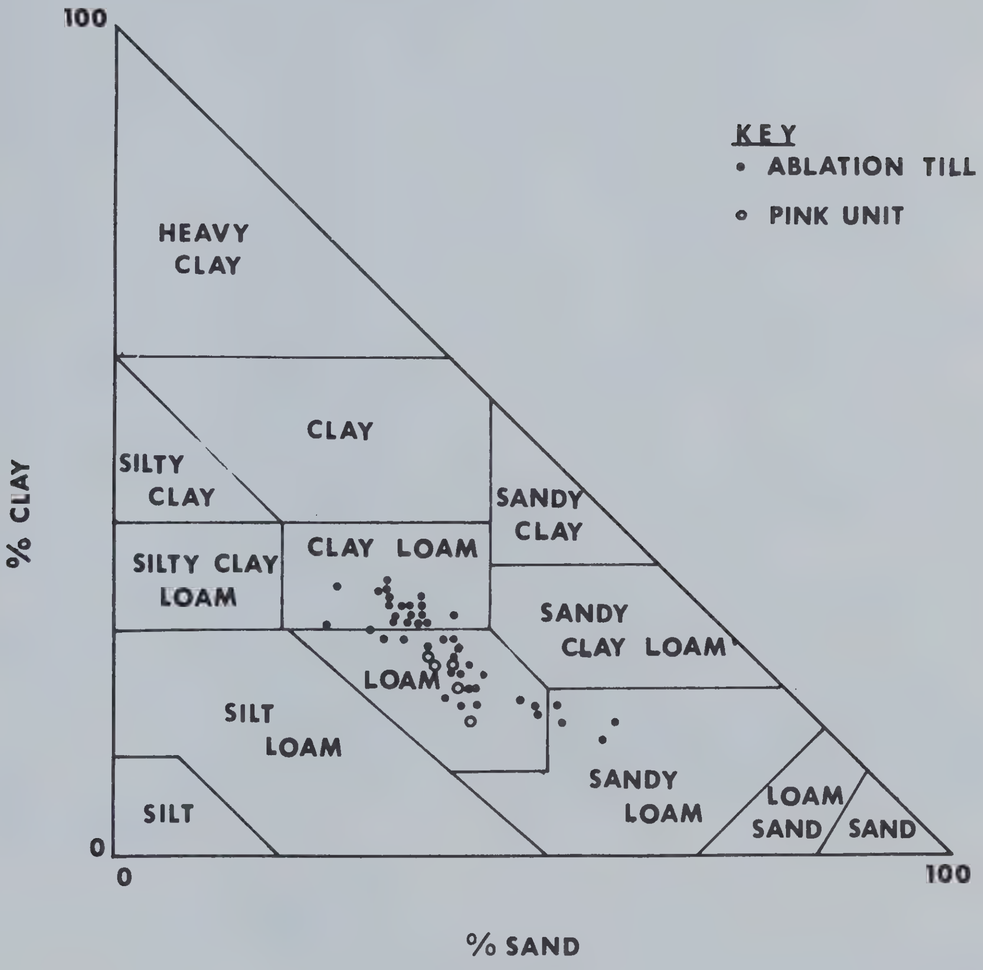


Figure 13. Diagram showing the textural composition of selected till and pink unit samples.

a) <u>1.00 - 2.00 mm. Fraction</u>

The lithology of this fraction is divided into the categories of acid and intermediate crystallines; basic crystallines; carbonates and locals. The latter group comprises material removed from the bedrock within a 200 mile radius of the Cooking Lake moraine. Such material mainly includes siltstone and fine grained sandstone. Appendix 1 presents the analytical data of this fraction.

In addition to the fact that acid crystalline material constitutes the bulk of all the till samples analyzed (i.e., 40% to 60%), other points are:

1. The vertical variations in lithology throughout both lower and upper tills show no distinct trends.

2. There are no significant differences between the lithologies of the lower and upper till units.

Figure 14 portrays the lithological assemblages of both till units in terms of the mean percentages of each rock type present.

b) <u>10 - 15 cms. Fraction</u>

The data of this size fraction analysis were acquired in the field by taking random counts of the components making up rock dumps located at frequent but well spaced intervals over the moraine. At each dump approximately 100 rocks were identified into the groups of acid, intermediate and basic crystallines; locals; Athabasca sandstone and Tertiary quartzite. The data of the analyses are presented in

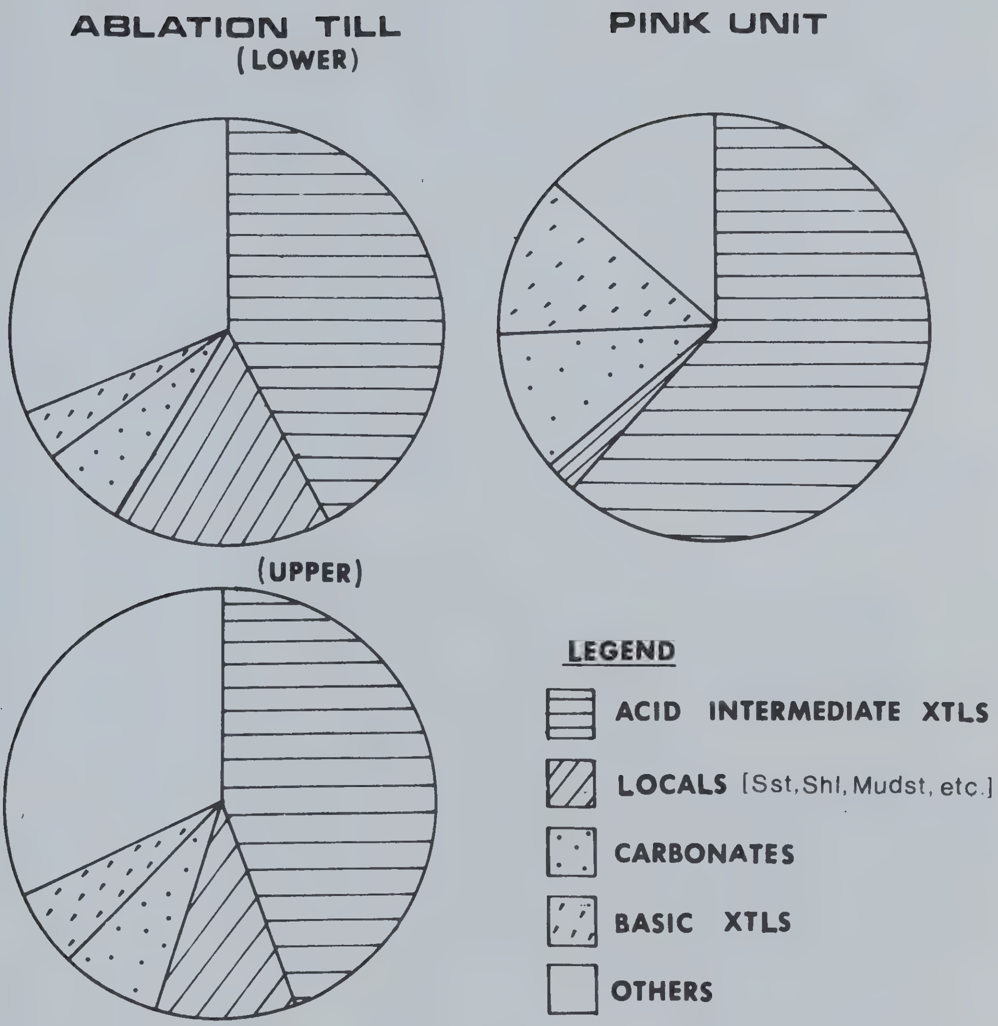


Figure 14. Diagram showing the lithological composition (1-2 mm fractions) of selected till and pink unit samples.

Appendix 2.

Eleven dumps were analyzed in this way, their locations being indicated in Figure 11. It is also assumed that the rock dumps are collections of rocks gathered in the close vicinity of each dump and that they were initially of upper till origin.

Figure 15 shows the lithology of the rock dumps. This size fraction provides a more accurate criteria for characterizing the lithology of the upper till, since the larger size of the individual components facilitates and improves identification over the 1.00 to 2.00 mm. fraction.

"Light" and "Heavy" Grain Mineralogy

Determination of the "light" and "heavy" mineral grain compositions inherent to both tills, was done using a standard heavy liquid separation technique.

Tetrabromethane was used as the separating agent with grains $<$ 2.96 S.G. being designated as "light" and grains $>$ 2.96 S.G. being "heavy." The size fraction of till used in this procedure was 0.125 to 0.0625 mm., i.e., namely, the very fine sand component. Samples of only one section were analyzed. The results are presented in Appendix 1.

a) The "Light" Grain Mineralogy

Feldspar (potassic and sodic) and quartz comprise the to most abundant species of "light" mineral grains. Together they make up $>$ 95% of the total mineralogy. Mica and calcite

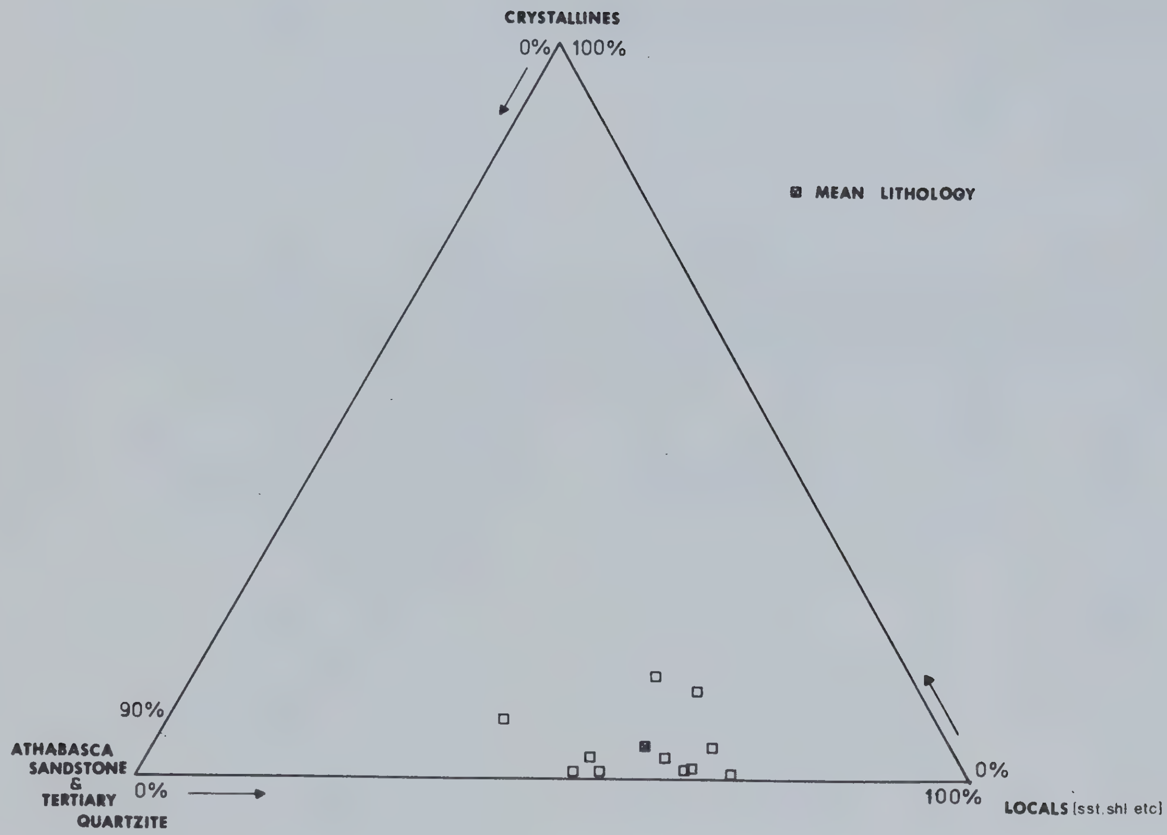


Figure 15. Diagram showing the lithological composition (10-15 cms fraction) of the upper till.

are of minor importance. The three silicate components together reflect the crystalline nature of the erratic content in the tills. The 1.00 to 2.00 mm. lithology for both tills verifies this. Figure 16 shows the mean "light" grain mineralogy for section 12375.

b) <u>The "Heavy" Grain Mineralogy</u>

Seven major groups of "heavy" mineral grain are identifiable in the tills. They are, in decreasing order of abundance, zircon, opaques, amphiboles, garnets, kyanite-sillimanite, spinel and tourmaline. Heavy minerals comprise approximately 27.1% of the mineralogy of both till units. Figure 16 shows the mean "heavy" grain mineralogy for section 12375.

Major, Minor and Trace Elements

Seventy-nine representative till samples were qualitatively analyzed for major, minor and trace element components using an x-ray fluorescence unit with a molybdenum tube which detects elements within the atomic number range 19 to 42. The following suite of elements were detected:

Major and minor elements:	K, Ca, Ti, Mn, Fe, Si
Trace elements:	Cu, Zn, Rb, Sr, Zr
Negligible amounts of:	Y, Pb, As, Ni, Cr

The data presented in Appendix 3 represent counts per 30 seconds for each element detected. Figure 17 shows a typical trace obtained during one analysis run. Comparing

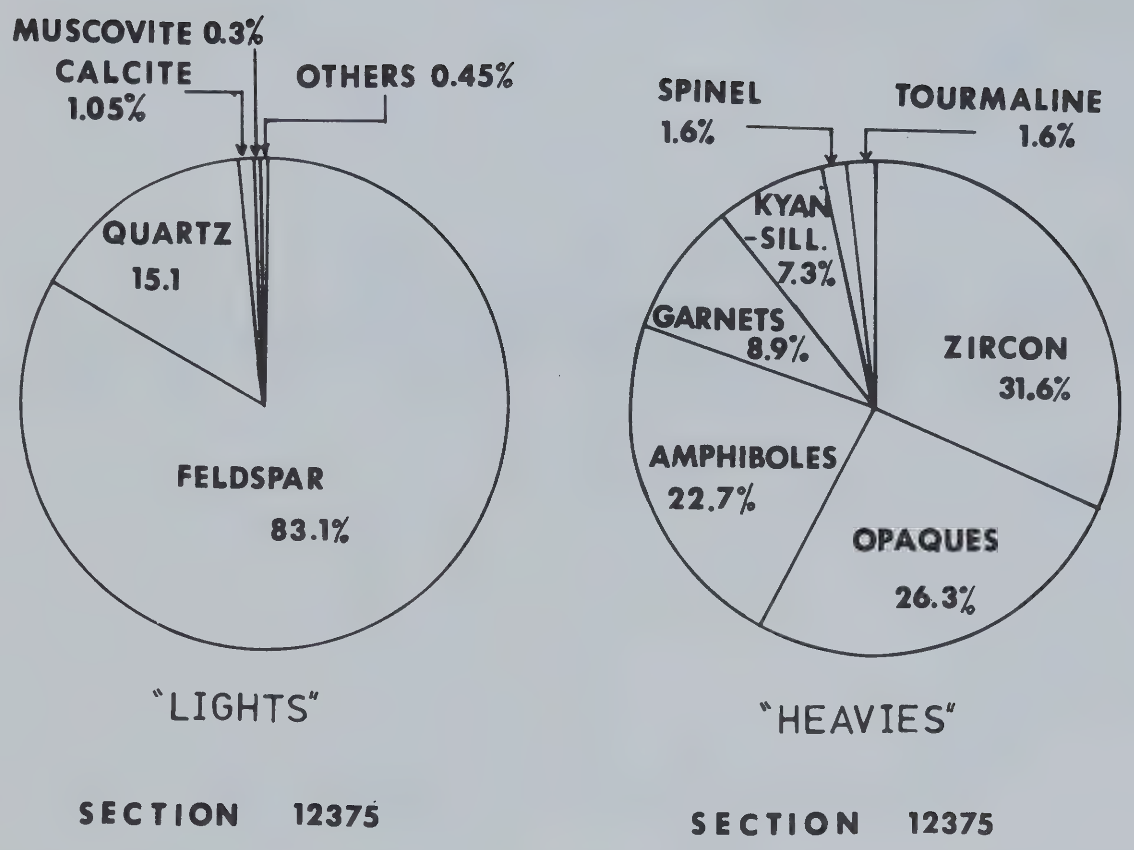


Figure 16. Diagram showing the "light" and "heavy" grain mineralogy of till samples located at SECTION 12375.

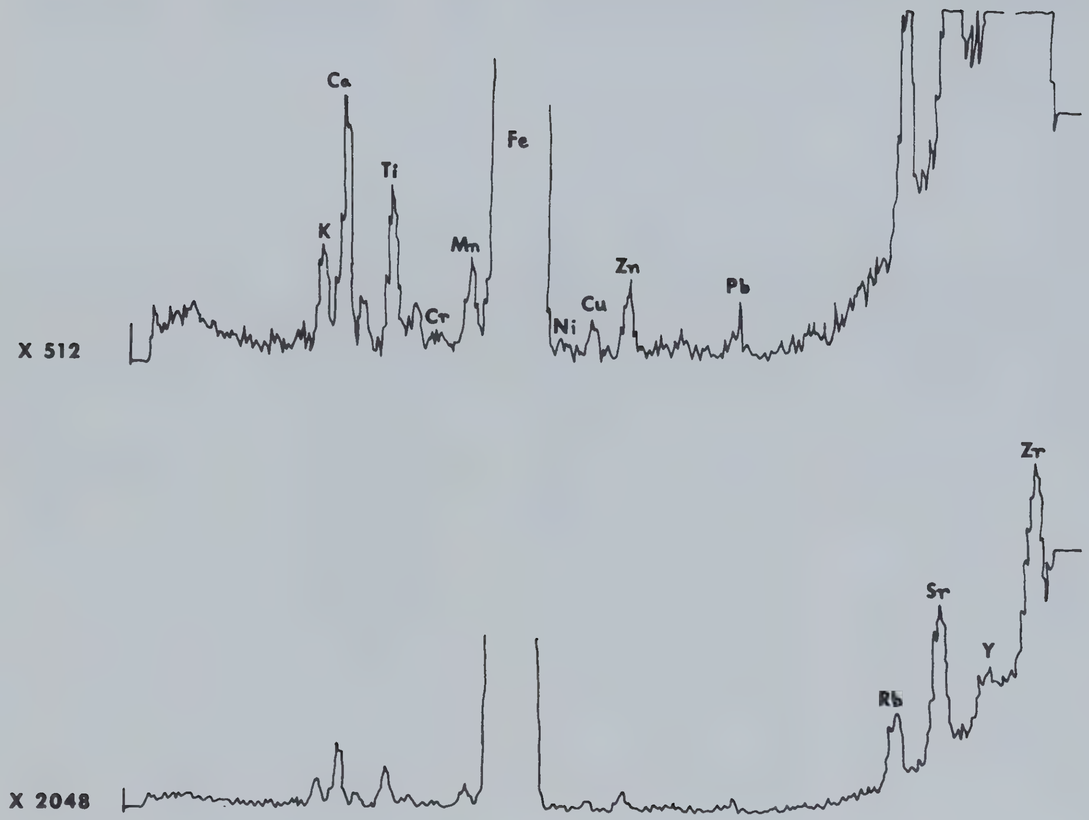


Figure 17. XRF traces showing the major, minor and trace element composition of a typical till in the moraine.

the heights of peaks on each trace quickly shows any differences in the element compositions of the tills.

Little variation is shown in major, minor or trace element abundance; certainly not significant enough to warrant any clear differentiation to be made between the lower and upper tills. The only element to fluctuate is calcium. Total iron content is very high and is second only to silicon.

The apparent high counts of the trace elements rubidium (Rb), strontium (Sr), zirconium (Zr) and yttrium (Y) are due to a drifting off the base line during analyses which in turn is due to the position of these elements close to the end of the molybdenum tube analyzing spectrum.

Carbonate Content

Analyses of carbonate content in the till samples were made using the Chittick technique devised by A. Dreimanis (1960). Slight modifications were made in sample preparation as follows:

One gram of < 230 mesh material was reacted with 50% HCl, compared to the traditional 1.7 grams of < 200 mesh material in 20% HCl. Tests were run on samples of different grain size and weight using variable acid concentrations. The results of the latter showed that the modified parameters outlined above, reproduced the same results as did those advocated by Dreimanis.

The main advantage of reacting the finer grade of

sample with the stronger acid is to save time.

The results, comprising percentage dolomite, percentage calcite, total percentage carbonate and percentage dolomite to total carbonate, are presented for each sample in Appendix 1. Figure 18 shows the constant relationship between percentage dolomite and percentage total carbonate.

For all samples analyzed, the total carbonate content does not exceed 20%, the mean being in the range 3.5 to 6.5%. Percentage calcite is lower than percentage dolomite in every sample by a factor of approximately 2 to 5%. There is no significant difference between the two till units of the moraine on the basis of carbonate content.

A NEW TECHNIQUE FOR CARBONATE DETERMINATION

The "Chittick" results were checked using a new technique of carbonate determination developed by C. M. Gold (University of Alberta, unpublished), and which operates on the principle that under a constant gas volume, increasing gas pressure can be calibrated to provide the volume of CO_2 given off from the given sample. The Chittick apparatus, instead, uses changing gas volume increase under constant pressure to give the same results.

One major source of error (i.e., temperature flux in the Chittick) is eliminated using the new procedure and any leak in the system is immediately detected on a print-out which is in turn connected to a pressure transducer which is

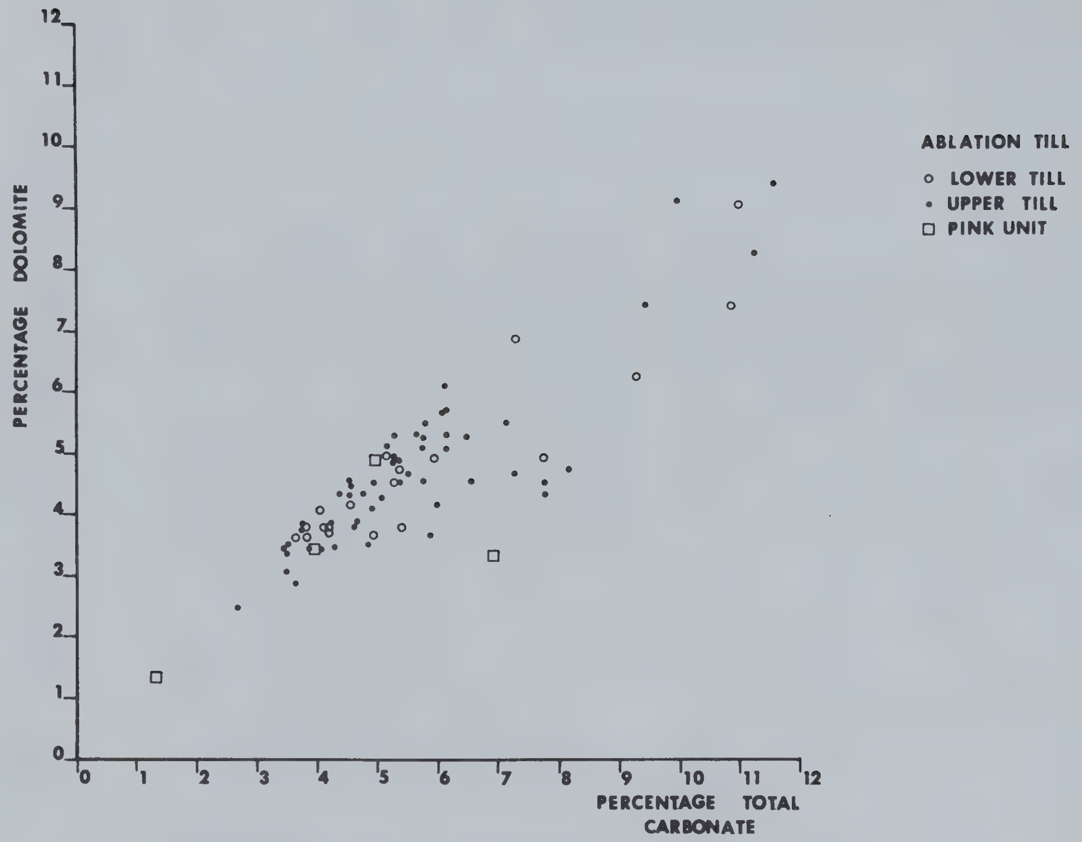


Figure 18. Diagram showing the relationship between percentage dolomite and total carbonate in selected till and pink unit samples.

the heart of the mechanism. The print-out also indicates when the reaction is over. The trace levels out at the point when no more gas is given off. A reproducibility of results to within 0.2% accuracy was obtained when checking the Chittick data using the new method.

THE "PINK" UNIT

In addition to the upper and lower tills which make up the Cooking Lake moraine, there is a third unit which is distinctive on the basis of its colour. This material is referred to, during the discussion, as the "pink" unit.

Occurrence and Physical Characteristics

There is a widespread occurrence of the "pink" unit throughout the Cooking Lake moraine. Stratigraphically it is usually situated at the interface between the lower and upper tills but it also occurs as disseminated lenses and wisps in the upper till. Nowhere does the pink unit occur in the lower till. The mean thickness of the unit is approximately 2½ inches. Appendix 4 presents the analyses.

Composition

Colour. The "pink" unit is distinct from the tills on the basis of its colour which is in the 10R Munsell range compared to the 2.5Y range of the upper and lower tills. It is therefore easily discernable both in hand specimen and when viewed at a distance.

<u>Lithology</u>. The "pink" unit is lower in local material, by approximately 9%, than the upper and lower tills and higher in basic crystallines by about 6% (Figure 13).

<u>Major, minor, and trace element mineralogy</u>. XRF analyses show that there is a higher potassium content in the pink unit than in the two tills. This, together with the fact that there is also a lower montmorillonite and higher illite content in the "pink" unit, suggests that clay mineral diagenesis played an important role in the alteration of the parent pink material. The potassium may reflect the feldspars present.

With respect to structure, texture, mineralogy and carbonate content, the pink unit cannot be discerned from the upper and lower tills of the moraine.

DISCUSSION

The preceding discussion shows that there are three criteria for determining two till units in the Cooking Lake moraine. These are colour, structure, and clay mineralogy.

The lithology and mineralogy of both till units indicate that ice advanced from the Shield area in the northeast corner of the province. Information relating to the chronology of these events is negligible and what there is is discussed in Chapter 8.

Both tills were deposited from stagnating ice sheets. The evidence for this is the characteristic landforms of the

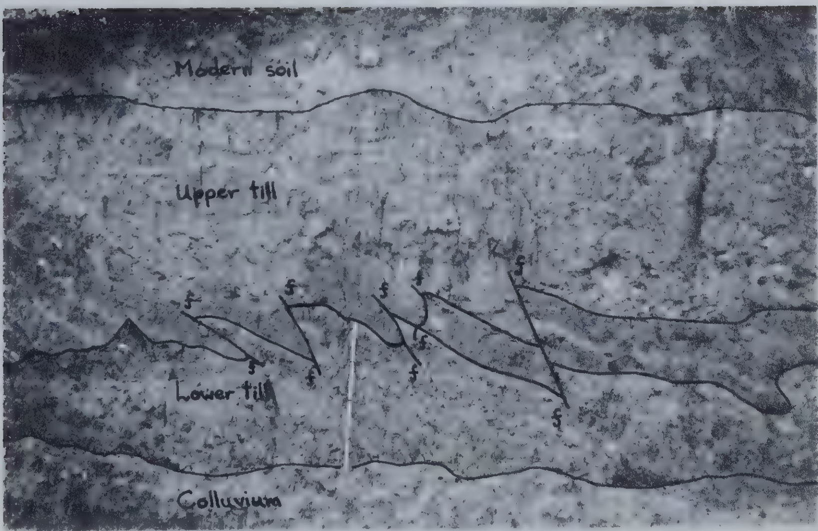
moraine and also the high illite content of both till units which is concluded to be a diagenetic product of montmorillonite break-down in a wet environment.

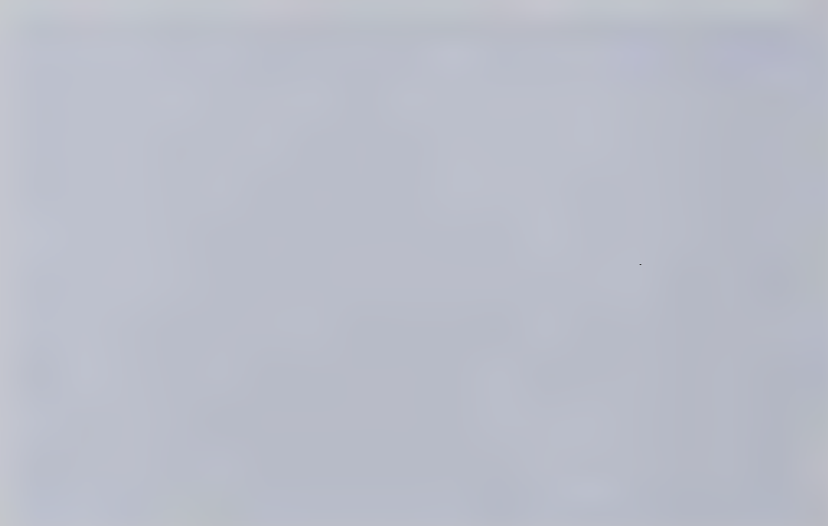
The pink unit, on the evidence of its stratigraphic occurrence and clay mineralogy is inferred to be a surface weathering horizon of the lower till. Its occurrence as lenses and wisps in the upper till is a result of overriding of the second ice advance and incorporation of the material into the ice prior to deposition with the upper till. The section in Plate 8 shows lower till having been ice-thrust up into the upper till along a series of sub-parallel fracture planes. This phenomenon explains the occurrence of the pink unit as inclusions in the upper till. The clay mineralogy of the pink unit also suggests formation under weathering conditions.

Plate 8

Section 12375 showing lower till having been thrust up into upper till along en echelon fracture planes. (Scale pole in foot divisions.)

PLATE 8





CHAPTER 4

SYNGLACIAL LANDFORM FORMATION

One of the main objectives of this study was to determine the origins and modes of formation of ice disintegration landforms in the Cooking Lake moraine. There are many theories attempting to outline the physical processes at work within an ablating ice sheet (Gravenor, 1955; Gravenor and Kupsch, 1959; Stalker, 1960; Parizek, 1969; Henderson, 1952). In the Cooking Lake moraine, field mapping revealed the existence of two dominant types of disintegration landform, namely prairie mounds and linear disintegration ridges which in themselves provide a criteria around which to test these theories.

ESTABLISHED THEORIES OF THE ORIGIN OF ICE DISINTEGRATION LANDFORMS

The "Let-Down" Hypothesis (Gravenor, 1955)

This theory pertains to the formation of ice disintegration landforms from the break-up of a structurally uncontrolled stagnating ice mass. The most common landform to occur throughout the moraine is the prairie mound. Landforms from controlled ice sheet stagnation (i.e., break-up along regularly spaced and oriented joint patterns) are very similar in physical characteristics to those produced from

an uncontrolled ice sheet in which there are no constraints to the manner in which the ice melts. The Cooking Lake moraine is a product of uncontrolled ablation for the most part.

Stages in the "let-down" hypothesis begin with heterogenous distributions of debris over the surface of a stagnating sheet of ice. Differential rates of melting below the cover take place. Areas with a thick cover melt slower than areas where debris is thinly distributed. This is a result of albedo differences between covered and uncovered ice. Pits result on the surface into which material slumps under gravity. These pits, having increased in cover thickness, now inhibit melting below so that there is a constant inversion of ice surface topography. Eventually, the bedrock on which the melting ice rests, will be reached and so the configuration which the drift cover attains upon coming to rest on the bedrock will be a function of the last topographic configuration of the ice sheet. Depressions in the summits of the drift hummocks will be due to the final melting-out of ice lenses in their centres.

The debris mantle is thus envisaged to be continually "let-down" onto the surrounding terrain through melting of the supporting ice underneath. The areas between hummocks are commonly draped with sand and gravel which are channel

fill deposits. Water in the channels flowed around the ice mounds. In the Cooking Lake moraine however, few inter-hummock areas are characterized by these deposits, due possibly to high rates of evaporation and radial runoff.

In 1959, Gravenor and Kupsch suggested that all types of uncontrolled landforms could result from a combination of "let-down" and "squeeze-up" processes, the latter being outlined later.

Field Evidence in Support of the "Let-Down" Hypothesis

Of several sections exhibiting good evidence in support of the "let-down" hypothesis, three are discussed below.

SECTION 9675 (53° 23' 10" N and 113° 13' 00" W)

As part of this section, a 2½ feet thickness of till overlies stratified sands and gravels. The section appears as a dome. The sands and gravels are in situ and have apparently been covered by the till subsequent to their own deposition. The following succession of events is proposed to account for the structural development of the feature which is shown in Plate 9 and diagramatically outlined in Figure 19.

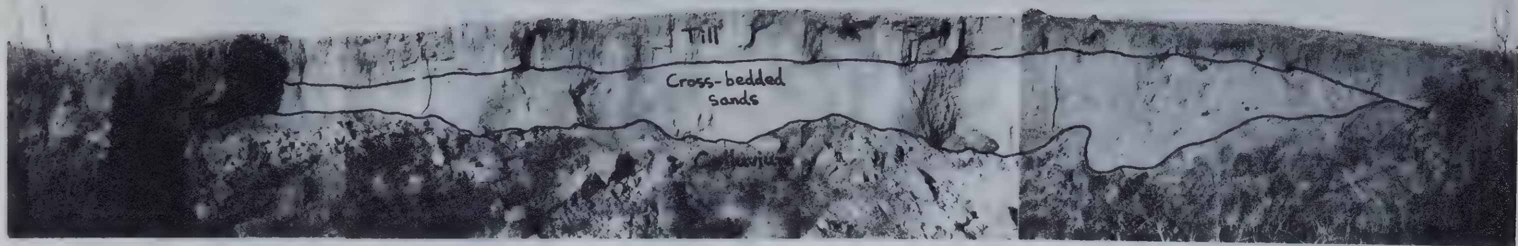
1. The sands and gravels were deposited by running water along the floor of a small ice-contact melt water channel. The banks of this channel were ice cored.

2. Differential rates of melting across the section resulted in the ice margins dropping below the water level

Plate 9

Section 9675 (53° 23' 10" N and 113° 13' 00" W) showing field evidence for the "let-down" hypothesis. (Scale pole in one foot divisions.)

PLATE 9



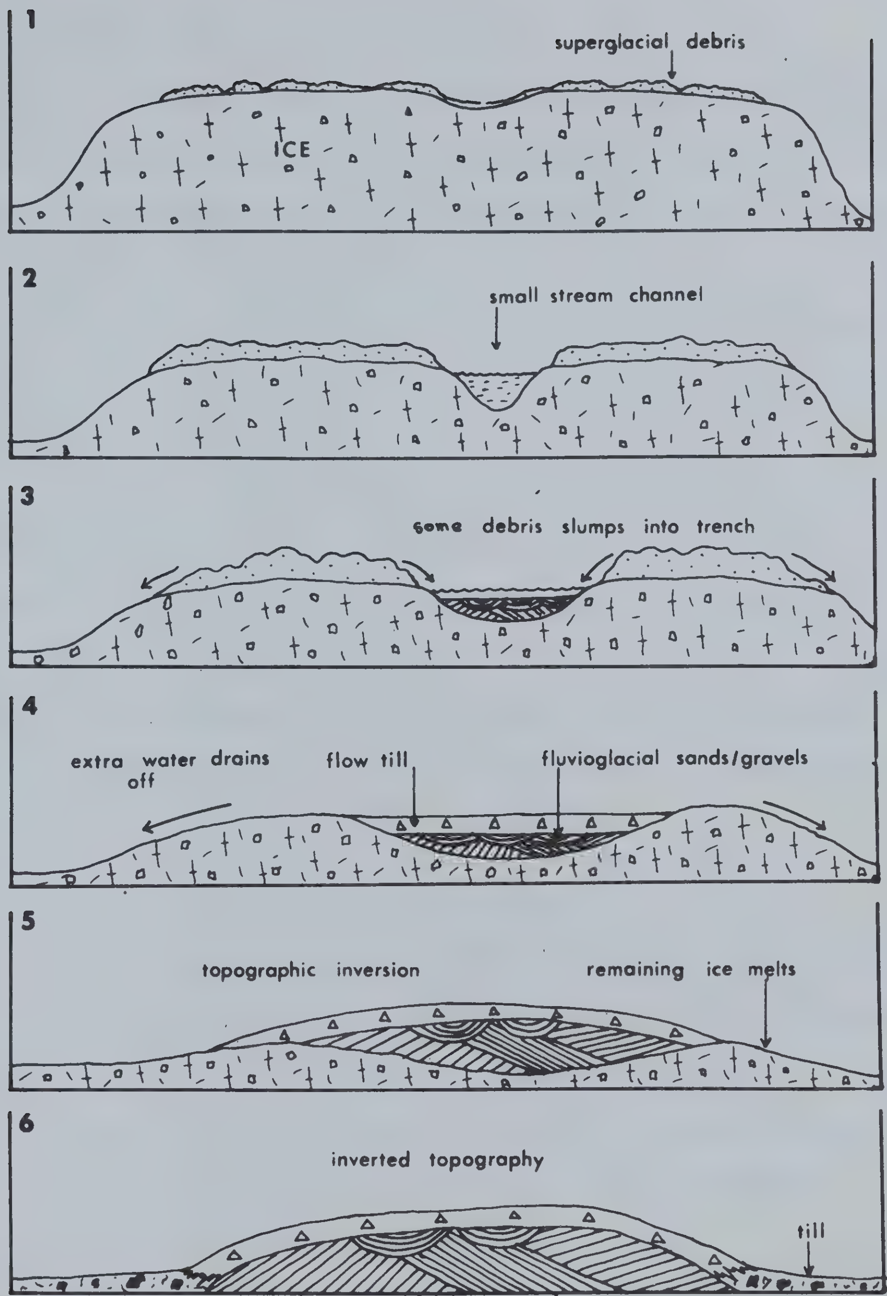


Figure 19. Sequence of diagrams explaining the formation of the landform exposed in SECTION 9675 (Plate 9).

in the channel which then drained.

3. At the same time as the channel drained, till slumped into the channel and over the fluvioglacial sediments. Sole markings with a 060-080° orientation at the base of the till are evidence of such a movement.

4. The banks dropped below the horizontal elevation of the channel floor resulting in the till being flexed over the sands and gravels to form a dome.

From the above process it is seen that the lowering of the channel banks is analogous to Gravenor's differential melting rates in ice which is mantled by a heterogeneous debris cover. The till has been "let-down" over the channel sands and gravels partly as an initial inflowing from the channel banks and partly from the "let-down" of the banks on either side.

SECTION 17475 (53° 22' 04" N and 112° 51' 40" W)

A band of flow till overlies laminated superglacial lacustrine silts and coarse sands which are rich with pockets of marl (Plate 10A). A modern soil profile extends 1' to 1½' into the till. The underlying lacustrine sediments have remained relatively stable with only a slight downward tilting away from the central apex of the dome.

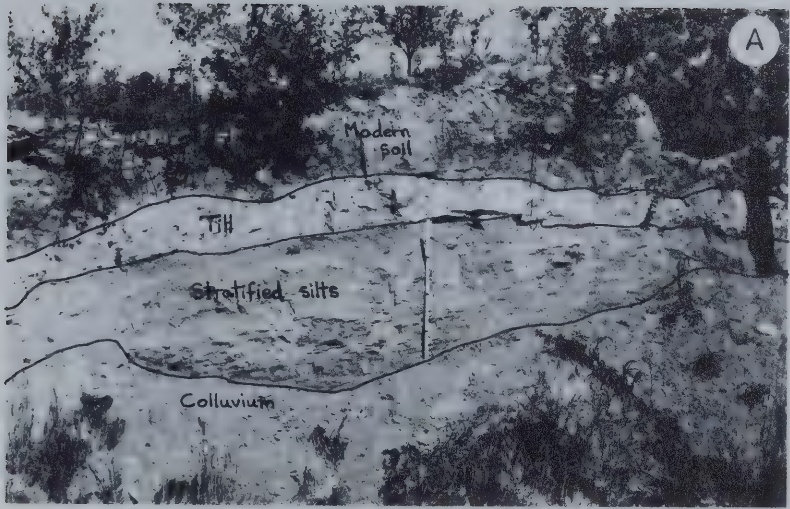
The mode of formation of this landform is assumed to be synonymous with that process described for the previous landform except in this case the silts and sands represent deposition in a superglacial lake and not a channel.

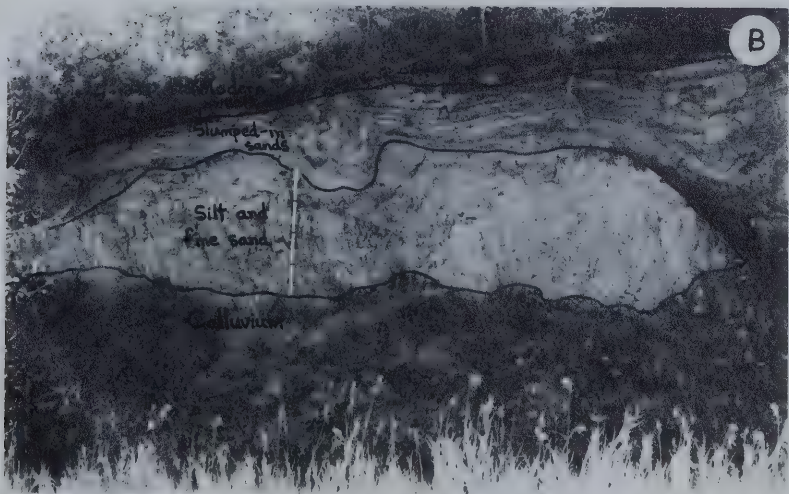
Plate 10

A. Section 17475 (53° 22' 04" N and 112° 51' 40" W) showing field evidence for the "let-down" hypothesis. (Scale pole in one foot divisions.)

B. Section 13275 (53° 34' 43" N and 113° 02' 45" W) showing field evidence for the "let-down" hypothesis. (Scale pole in one foot divisions.)

PLATE 10


A
Modern soil
Till
Stratified silts
Colluvium


B
Slumped-in sands
Silt and fine sand
Colluvium

No primary sole structures exist on the underside of the till which slumped into the lake, covering the lake bottom sediments which now comprise the core of the landform.

SECTION 13275 (53° 34' 43" N and 113° 02' 45" W)

This section is composed of coarse sand and gravel bands that have been draped over lacustrine silts (Plate 10B). The original lake drained as a result of the melting of sub-surface ice.

As the lake sediments were exposed, rupturing occurred to produce cracks into which lag material slumped from the banks.

Subsurface ice on either side of the lake must have occupied a greater volume than the ice directly beneath the lake for the topographic inversion to occur. The melting rate of the ice beneath the lake may however have been increased by greater heat transfer through the water.

<u>The "Squeeze-Up" Hypothesis</u> (Stalker, 1960)

Although Gravenor and Kupsch (1959) had suggested a "squeeze-up" process to account for ice disintegration land-form development, it was not until a year later that the idea of semi-consolidated material being squeezed-up into crevasses from the base of a stagnating ice mass, arose. G. Hoppe showed in the Norrbotten region of southern Sweden that this process may be applied to explaining the formation of the rim ridges of moraine plateaux (not present in

the Cooking Lake moraine), linear ridges and also prairie mounds in which the rim ridges are tightly closed.

During the advanced stages of ice stagnation, crevasses and holes open up and eventually extend to the base of the ice sheet at which point there is a sudden release of pressure which has built up along the ice-bedrock interface. Semi-consolidated drift is then squeezed up into the crevasses and holes under the pressure of the overlying ice burden to a height which is in equilibrium with the physical forces operating. A distinct fabric would also tend to evolve in the squeeze-up material as a result of this upward movement.

Field Evidence in Support of the "Squeeze-Up" Hypothesis

In comparison to abundant field evidence supporting a "let-down" hypothesis for ice disintegration landform development, there are fewer localities at which the landforms can be argued to have formed by a "squeeze-up" mechanism. One such locality is that of section 12375.

SECTION 12375 (53° 32' 30" N and 113° 01' 22" W)

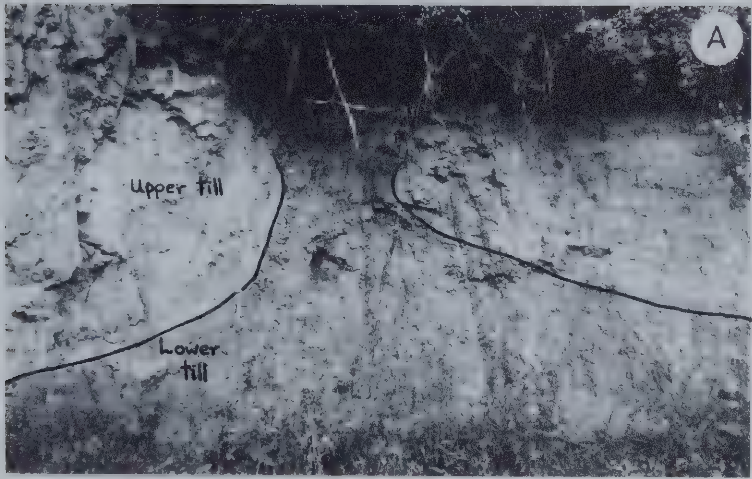
The upper and lower tills are present in this section. The lower, darker till, has been squeezed up into the upper unit, the movement producing distorted structures and foliation in the upper till at the interface between the two units (Plate 11A). For this to take place, the lower unit must have been in a semi-saturated state prior to ice advance

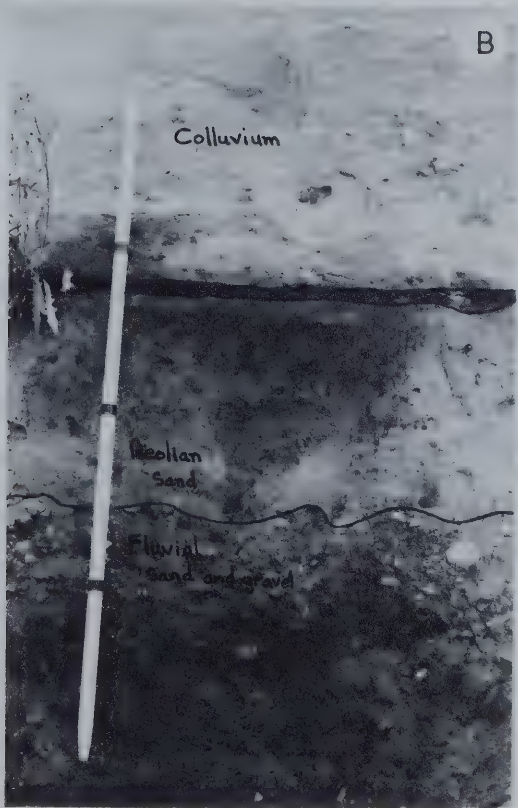
Plate 11

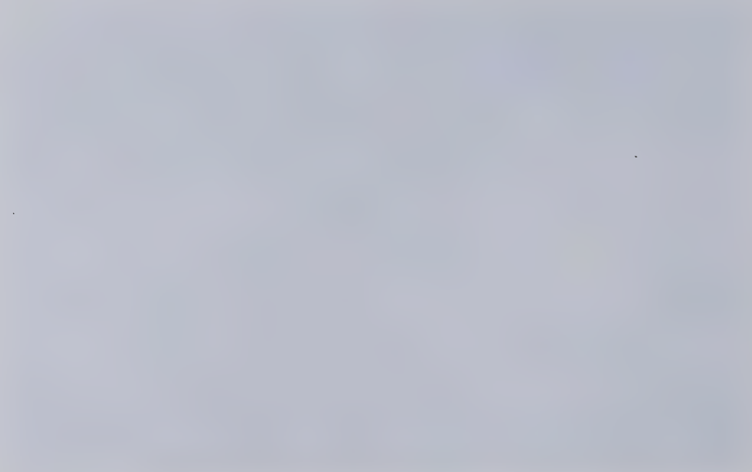
A. Section 12375 (53° 32' 30" N and 113° 01' 22" W) showing field evidence for the "squeeze-up" hypothesis. (Scale pole in one foot divisions.)

B. Close-up view of the delta (Plate 2A) showing 1 foot of wind blown sand overlying fluviatile sands and gravels. (Scale pole in one foot divisions.)

PLATE 11


A
Upper till
Lower till


B
Colluvium
Eolian Sand
Fluvial Sand and gravel



over it, or else the water base of the ice sheet depositing the upper till, must have been sufficient to remobilize the lower unit and cause secondary reworking. The latter is more viable because the period of time between the two episodes of ice stagnation in the moraine area was long enough to permit the development of a weathering horizon on the surface of the lower till unit. In section 12375 there is, in the lower till, an orientation of joints parallel with the general configuration of the convolution itself. Figure 20 explains the formation of the landform shown in Plate 11A).

<u>The "Slump-In" Hypothesis</u> (Parizek, 1969)

In 1969, R. Parizek advanced a slightly different hypothesis to explain the formation of ice-contact ridges and prairie mounds. Although he did not personally entitle his ideas as "slump-in" phenomena, it is applicable in this study.

1. Melting of the ice sheet is accentuated along joints and crevasses which open up to the underlying bedrock over which the ice has moved and subsequently disintegrates.

2. The ice is rich in debris which slumps off the surface into the crevasses, building up to form either a mound of debris at the bottom of a hole, or a ridge at the base of a linear crevasse.

3. Ice-contact rims build up around or along the margins of these slumped-in mounds.

4. The ice on either side of the mound or ridge melts

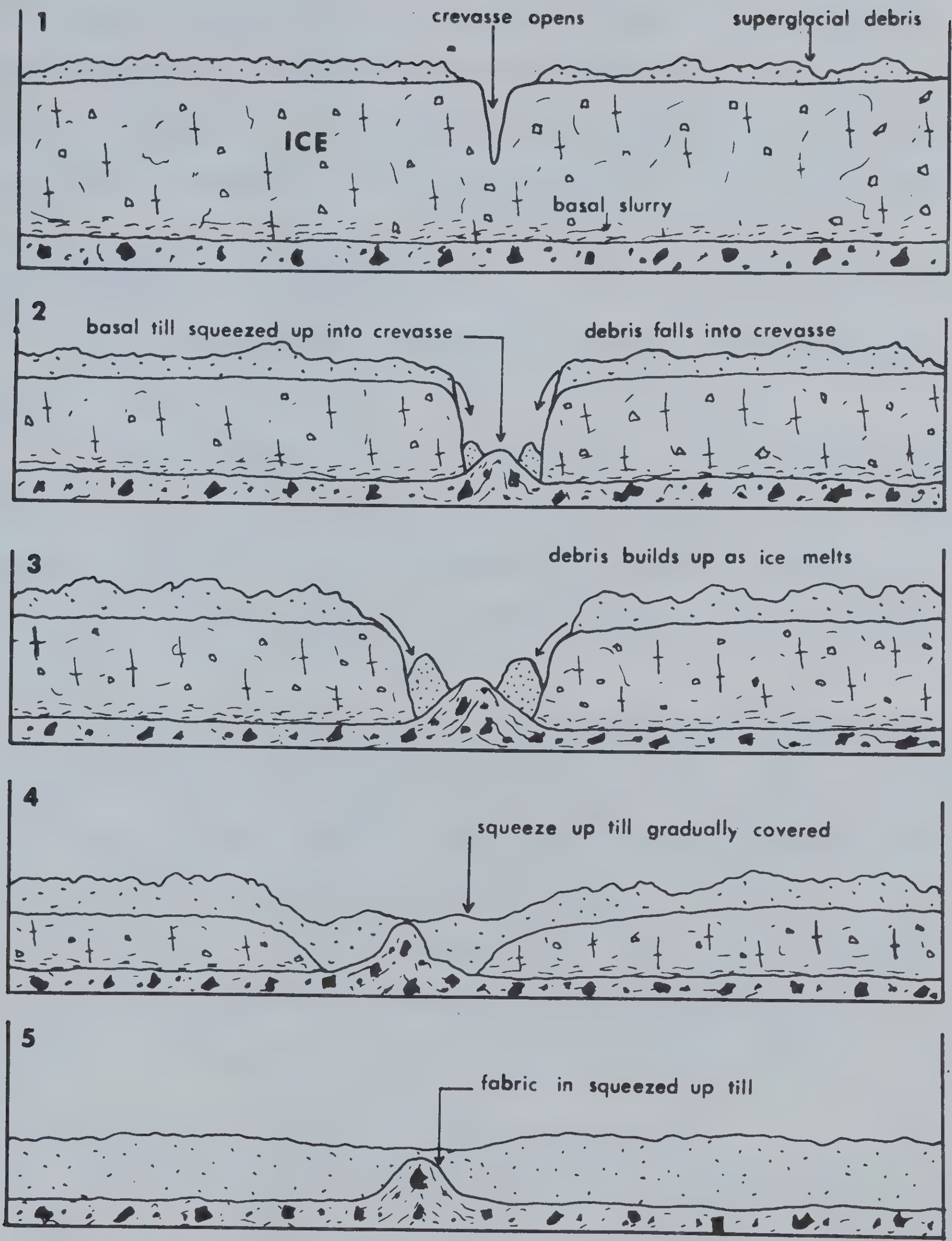


Figure 20. Sequence of diagrams explaining the formation of the landform exposed in SECTION 12375 (Plate 11).

and disappears leaving the slumped in debris as upstanding landforms which are usually characterized by a rim and a central depression as in the case of a prairie mound. The impounded lake drains out through a breach in the rim ridge.

<u>Field Evidence in Support of the "Slump-In" Hypothesis</u>

The Cooking Lake moraine has several landforms which support Parizek's theory.

The section at 53° 32' 25" N and 113° 03' 00" W (Plate 4) shows coarse, poorly sorted sands and gravels slumped into a superglacial depression, quite possibly the result of stage 2 in the above process. Figure 21 explains the formation of the section.

Throughout the moraine there are several instances where prairie mounds possess incomplete rims. It is feasible that such breaches resulted from superglacial lake drainage during stage 4 of Parizek's hypothesis.

Additional field evidence in support of the "slump-in" hypothesis pertains to the frequent slumping-in and blocking of stream trenches over the moraine.

<u>The Periglacial Hypothesis</u> (Henderson, 1952)

The following thesis, advanced initially by Henderson in 1952, contends that periglacial conditions play an important role in developing landforms such as those discussed above. He believes:

1. Frozen ground in front of an advancing ice sheet

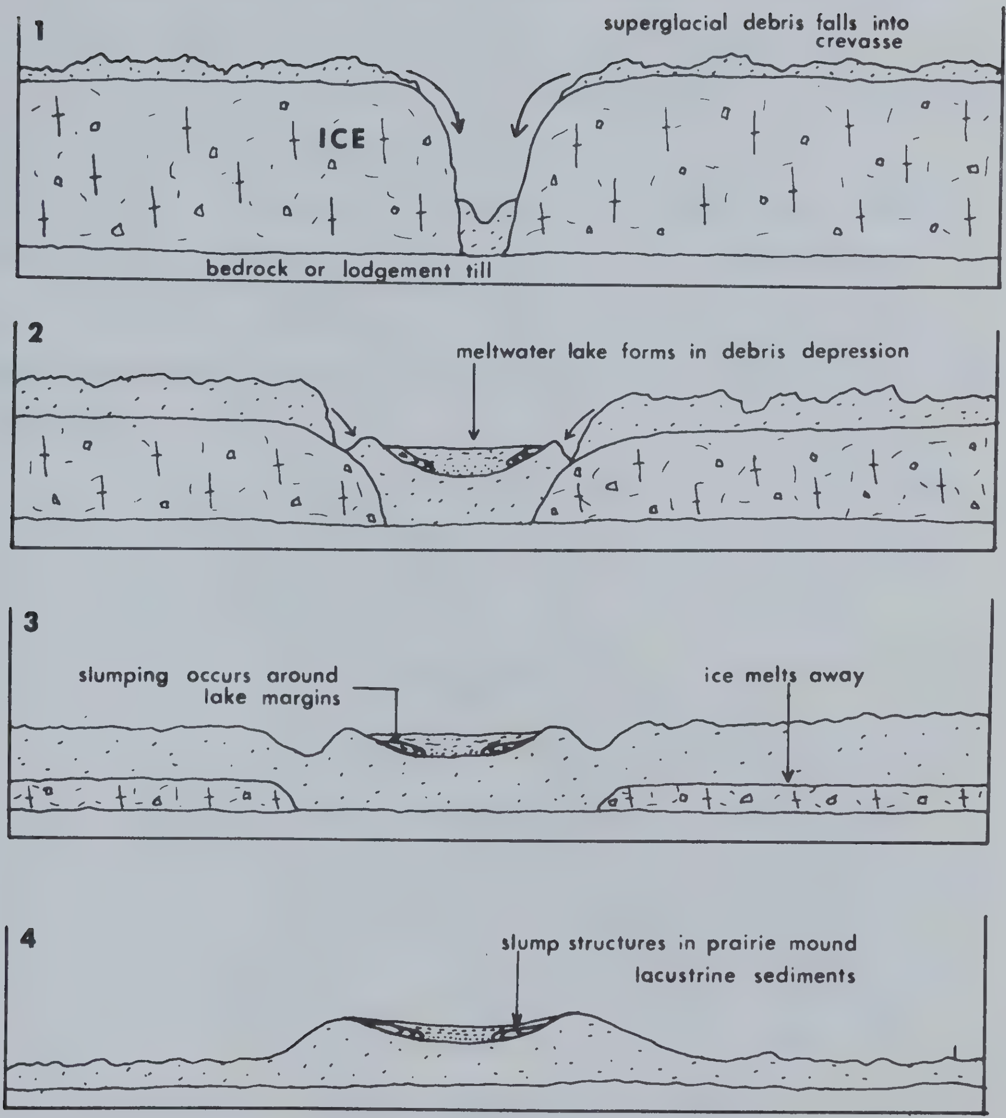


Figure 21. Sequence of diagrams explaining the formation of the landform exposed in SECTION 11575 (Plate 4).

contracted and produced polygonal cracks.

2. The cracks developed into ice wedges in which ice growth exerted a lateral pressure in all directions.

3. Bulging of the enclosed earth material occurred with the subsequent development of an ice core.

4. With the passage of periglacial conditions, the ice lens melts to form a central depression in the hummock.

There are however several difficulties with this hypothesis with respect to its viability in the Cooking Lake moraine.

Firstly, it does not account for linear till formations and secondly, no evidence of ice wedges has yet been found anywhere on the moraine.

CONCLUSION

It is inferred from field evidence that the "let-down", "squeeze-up" and "slump-in" processes are jointly responsible to varying degrees in the evolution and physical development of the landforms of the Cooking Lake moraine. The order in which they are listed here reflects their order of importance in fashioning the moraine topography. However, with new sections exposed from road construction activity, more conclusive evidence relating to these hypotheses will become available.

CHAPTER 5

THE EARLY POSTGLACIAL ENVIRONMENT

Physiography

Sands in the northern half of the moraine occur in thicknesses ranging from several inches to as much as three feet over topographic highs and in depressions. Plate 11B shows a 1' thick wind blown sand layer overlying fluviatile sands and gravels in the main exposed section of the delta approximately 1½ miles west of the Elk Island Park west gate.

Origin of the Sands

Initial ideas relating to the origin and deposition of the sands, centred around a fluviatile transporting medium but subsequent scanning electron microscopic analyses indicated appreciable percentages of grains having surface textures which suggest an aeolian mode of transportation. Plate 12 shows the two types of grain surface sculpturing. The samples used in this study were taken exclusively from Elk Island National Park. Figure 22 shows the sampling locations.

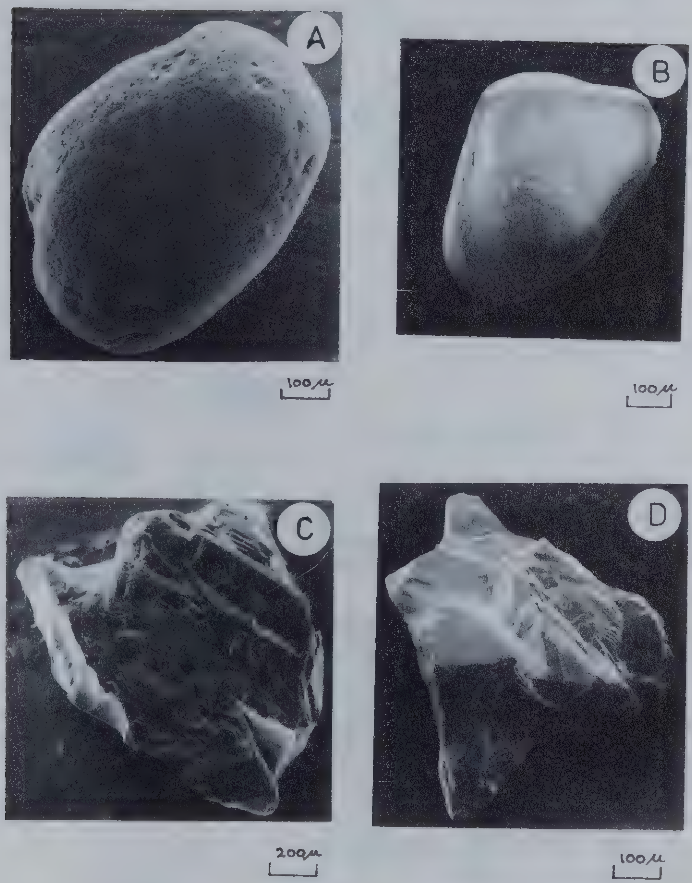
To track down the source of the wind blown sand component, it was necessary to consult the weather records for the area with respect to determining annual wind pattern behaviour over the longest period of time for which such records exist. Data were initially recorded at Edmonton

Plate 12

A and B. Scanning electron micrographs of typical wind blown sand grains.

C and D. Scanning electron micrographs of typical water transported sand grains.

PLATE 12



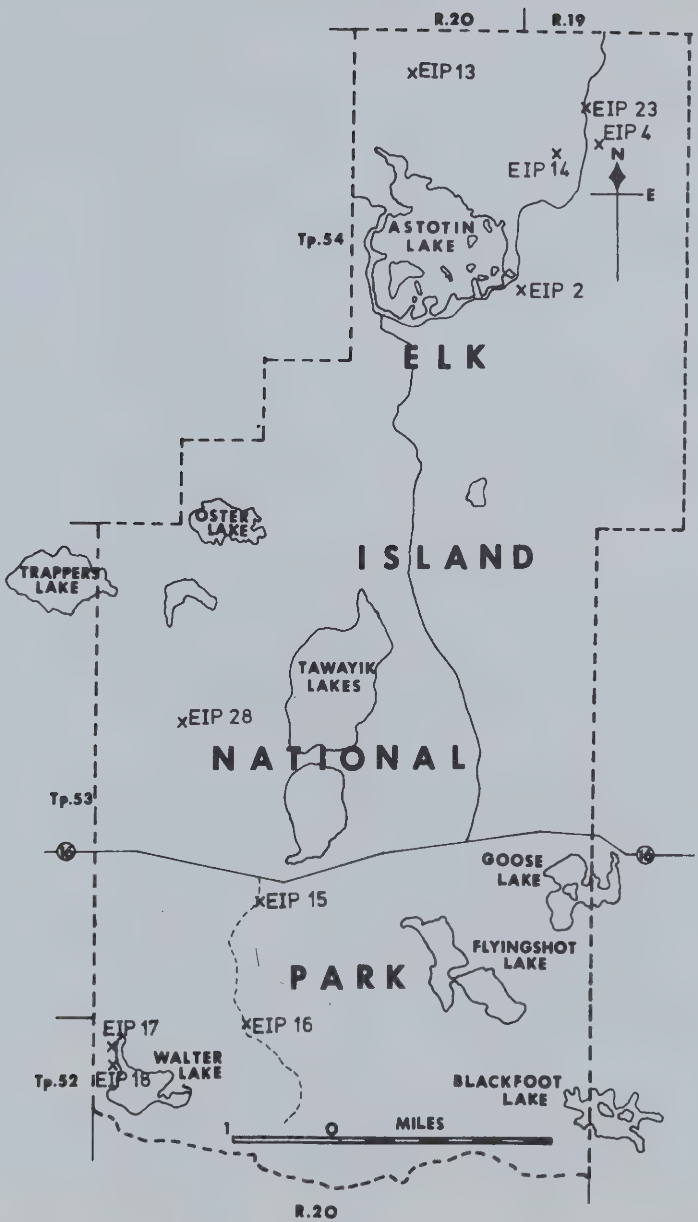


Figure 22. Map showing the sampling locations of surficial sands in Elk Island National Park.

Industrial Airport and go back to 1945. Figure 23 summarizes the wind direction data.

The dominant mean annual wind direction over the winter months is south to south-west, whilst during the summer months (May to September inclusive) the dominant direction from which the wind blows is the north-west. Any material which is likely to be wind blown will be transported during the summer months when the surface of the land is dry and free of snow. However the fairly coarse texture of the sand on the moraine, suggests that they would not have been moved very far.

Two possible sources are the sand dune complex north of Fort Saskatchewan lying between the Sturgeon and Redwater rivers and the dried out floor of glacial Lake Edmonton just after it drained.

The assumption is also made that wind directions were the same as they are over the area today. It is likely, from field evidence, that the winds were carrying material at a time when superglacial lakes were still existing over large tracts of the moraine. This is inferred from the intermixing of aeolian sand grains with sands and gravels of fluviatile origin in superglacial lacustrine successions.

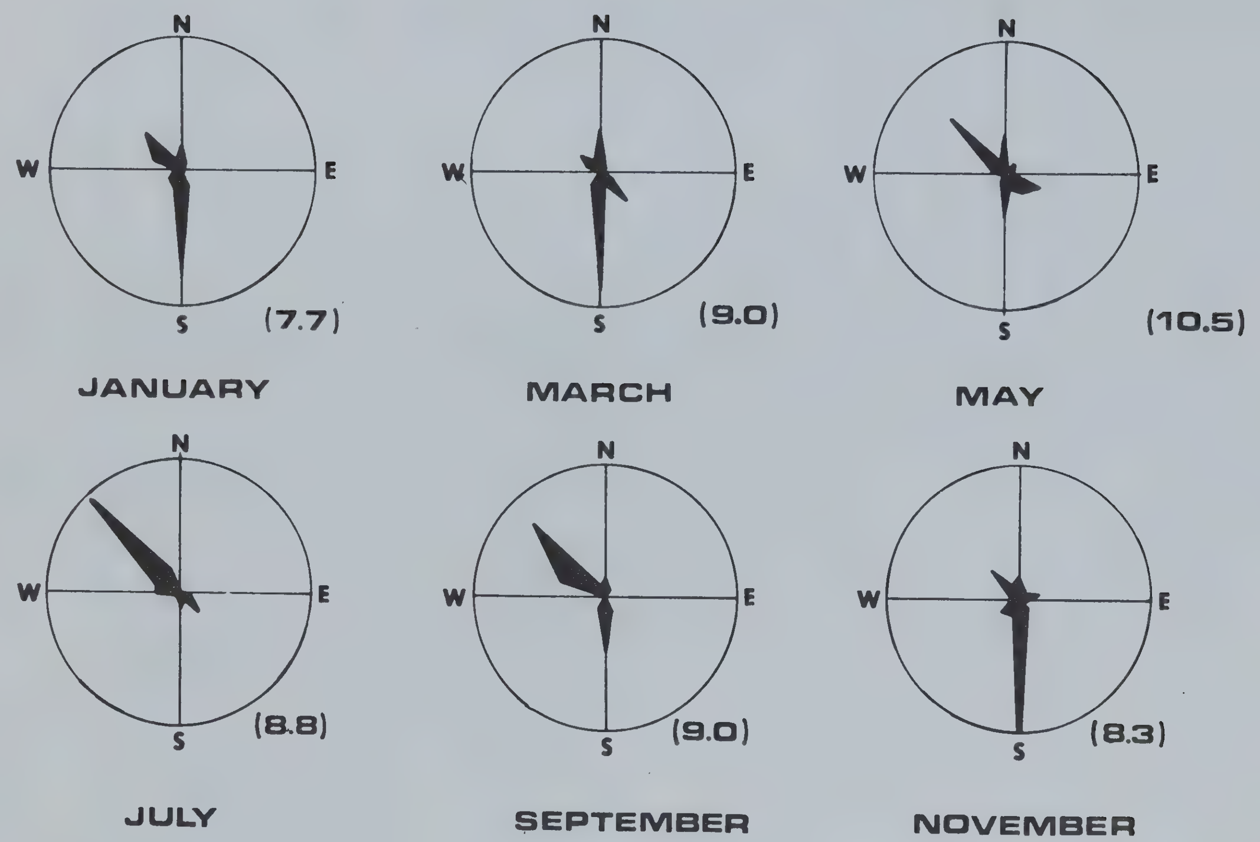


Figure 23. Diagrams showing the dominant wind direction at various times throughout the year over the northern half of the moraine.

CHAPTER 6

LATE GLACIAL-EARLY POSTGLACIAL FAUNA OF THE MORAINE

Field evidence indicates that a relatively rich faunal assemblage had begun to colonize the moraine at the beginning of postglacial time. This is supported by the following evidence. Firstly, all fossil freshwater molluscan and algal remains are found in superglacial lacustrine sediments. Secondly, many prairie mound sections show distinct, poorly-sorted slump structures in these sediments and thirdly, three C14 dates of the fossil shell material, yield ages of 10,880-9,050 years B.P. Table 1 outlines the major faunal groups with a small description of their habitats. Plate 13 is a collective representation of the different species.

Most of the fossil mollusca inhabited permanent shallow water bodies which usually had muddy bottoms and aquatic vegetation which was usually enriched with ostracods and the thalluses of Charophytes. <u>Pisidium ferrugineum</u> Prime shows a preference for cool conditions which is in accordance with what would be expected in the environment of a stagnating ice sheet.

Several points should be noted. Firstly, in modern analogues of stagnating ice masses, such as the temperate

Table 1

List of Superglacial Lacustrine Fauna of the Cooking Lake Moraine

Group	Species	Palaeoenvironment	Relative* Abundance	SO^{18}_{PDB} Content
Gastropoda	Stagnicola elodes (Say)	Widespread. Temporary and permanent pools of tundra. Stream species. Prefers vegetation.	C	-9.54 to -12.34
	Lymnaea stagnalis appressa (Say)	Permanent water bodies. Tundra species found commonly in permanent and intermittant streams. Abundant vegetation.	C	--
	Physa jennessi skinneri (Taylor)	Tundra species. Shallow ponds and in streams. Prefers muddy bottoms of lakes.	R	--
	Gyraulus parvus (Say)	Lives on aquatic vegetation in lakes, ponds and streams. Common tundra species. Prefers muddy lake bottoms.	S	--
Bivalvia	Pisidium ferrugineum (Prime)	Tundra lakes and ponds. Partial to cool climate. Summer temps. did not exceed 21° C.	C	-6.07 to -7.00
	Pisidium casertanum (Poli)	Lakes and ponds, especially bog ponds and swamps that dry up for several months of the year. Tundra species.	S	--
Charophyta	Chara sp.	Lakes and ponds. Water rich in calcium bicarbonate. pH, 7.4 - 8.7.	A	-6.74
Ostracoda	2 species (?)	?	S	--

*Abreviations for Relative Abundance:

R - rare (<5 specimens per several pounds of bulk sample).

S - scarce

C - common

A - abundant (>100 specimens per several pounds of bulk sample).

Plate 13

Scanning electron micrographs of:

A. Stagnicola sp.

B. Lymnaea stagnalis.

C. Physa jennessi skinneri.

D. Gyraulus parvus (Say).

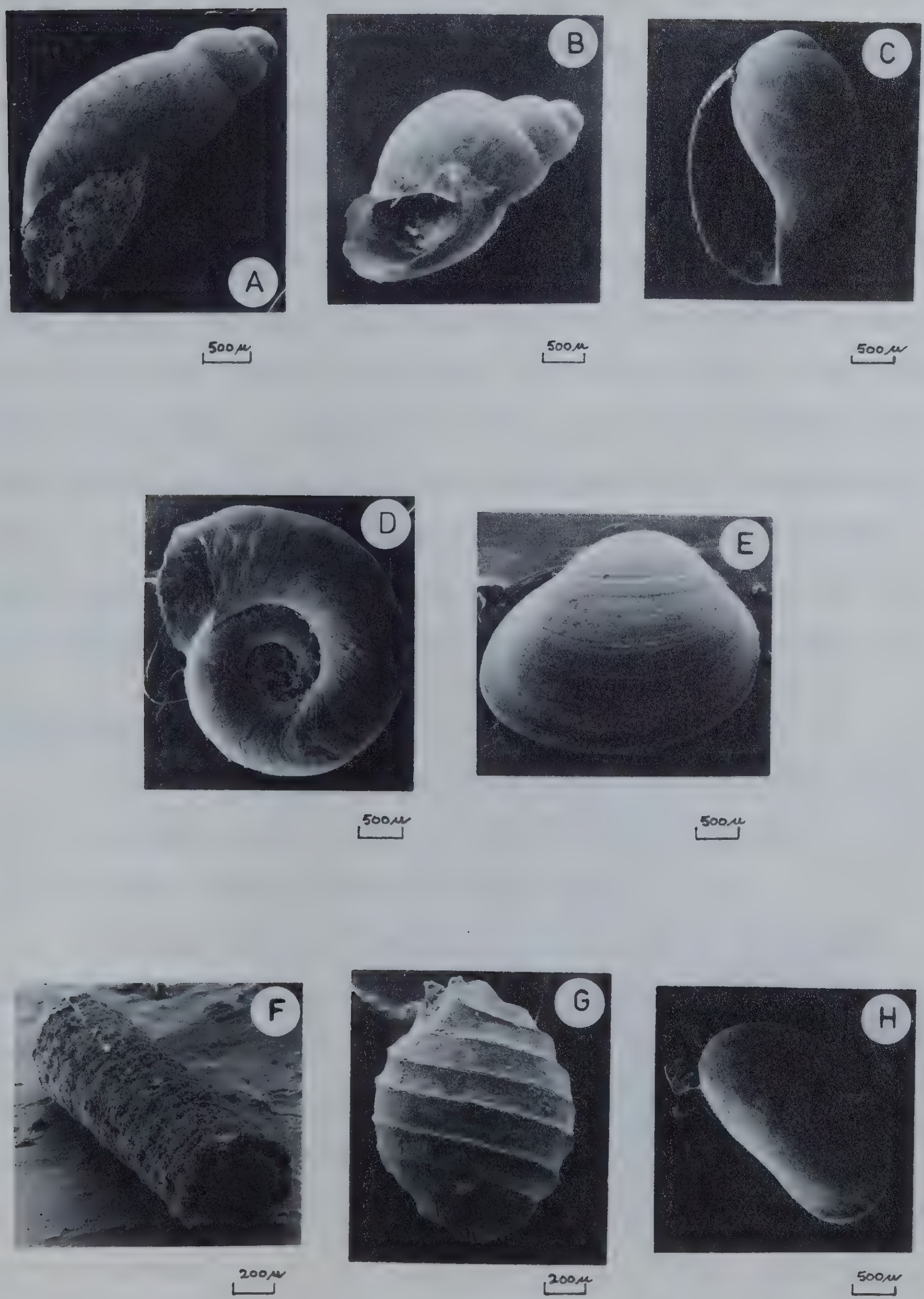
E. Pisidium sp.

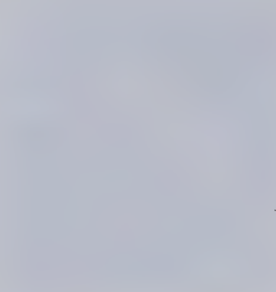
F. Chara. Stem Fragment.

G. Chara. Oogoniocarp.

H. Ostracod (unidentified).

PLATE 13







glaciers of South Island, New Zealand, ice blocks may remain buried in drift far from the receding part of a valley glacier and remain in such a state for a considerable period of time. It is feasible, therefore, to assume that ice may have remained even longer under a drift cover which insulated it in a cold environment such as would have prevailed in the Cooking Lake area at the end of glacial-early postglacial time. Thus, ice may very well have remained buried in drift long after the onset of a climatic amelioration. The point being made here is that small lakes were quite possibly in existence over the moraine for an appreciably long period of time, i.e., they spanned the glacial-postglacial boundary. The organisms growing in them may have been more a function of a warmer postglacial climate than of a cold glacial one.

Oxygen Isotope Analyses

The objective of this study was to prove that evaporation played a major role in the disappearance of the superglacial lakes over the moraine (Westgate, 1976).

Oxygen isotope analyses on six species of fossil freshwater molluscs showed a variation in δO^{18} content ranging from -6.07 to -12.34. Accurate interpretations of the results are difficult and somewhat tenuous since the following factors are not accurately known:

a) the oxygen ratio of the water in which the organisms lived.

b) the mean annual precipitation in the area.

c) the extent, if any, of inflowing and outflowing water.

d) the temperature of the lake water throughout the year.

Fritz and Poplawski (1974) conclude that O^{18} enrichment in freshwater molluscs is controlled by the rate of evaporation in lakes and that the amount of precipitation in the past was similar to that of the present, i.e., low at only 10" - 20" per annum for east-central Alberta. It is assumed that lakes over the Cooking Lake moraine were stagnant from the time of initial colonization. The second of Fritz' controlling factors can thereby be ignored and the high O^{18} content of the Cooking Lake shells thus inferred to be a function of evaporation only.

Discussion of Results

There are very close similarities between the fossil shell carbon-13 and oxygen-18 isotope data obtained in this study and the data acquired from freshwater molluscs living in the small lakes and ponds of southern Saskatchewan, Ontario and Michigan today (Keith *et al.*, 1964). The latter data show a δO^{18}_{PDB} mean value of -9.2 which is comparable to the -9.0 value for the Cooking Lake shells. Mean values for the δC^{13} contents of ostracod shells taken from the bottom three metres of sediment in Wabamun Lake (40 miles due west of Edmonton) are in the same range as the Cooking Lake mollusca. The ostracods were located below the 10,500 B.P. ash layer which consequently indicates an age of approximately 11,000 to 13,000 years B.P. (Fritz and Krouse, 1973).

Conclusions

It is concluded from the above discussion that the different species living in superglacial lakes over the moraine during late glacial-early postglacial time preferred lakes which were shallow and of small extent. Most lakes were in the order of 30 to 40 feet in diameter and 6 feet deep.

During winter time the lakes were frozen and little change in the O^{18}/O^{16} content occurred. In summer, appreciable evaporation of O^{16} would occur causing a proportional enrichment in O^{18}. Differences in the O^{18} contents of the different species present are almost certainly related to different growth rates and the temperature of their habitat (Figure 24).

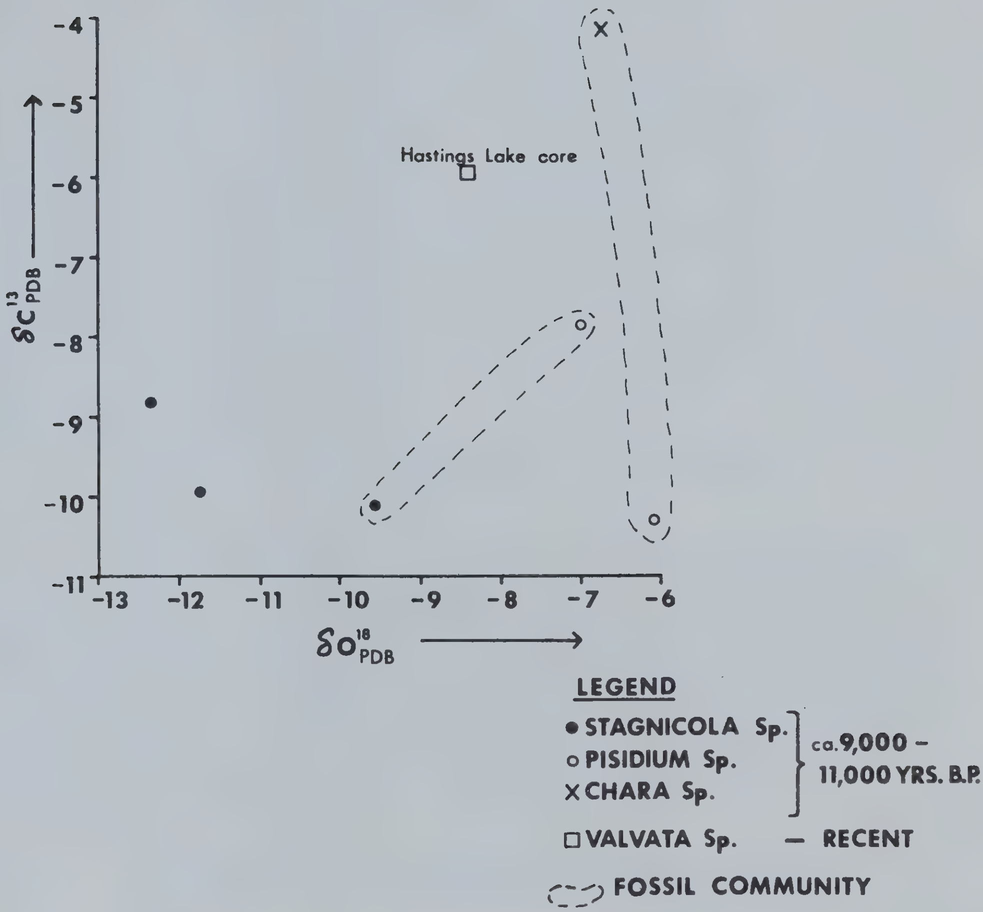


Figure 24. Diagram showing the δC^{13}_{PDB} - δO^{18}_{PDB} composition of several groups of superglacial lacustrine fauna.

CHAPTER 7

THE GEOLOGICAL EVOLUTION OF THE COOKING LAKE MORAINE

Although many topics relating to the geological and topographic evolution of the Cooking Lake moraine have been discussed in previous chapters, it is necessary to briefly reiterate the conclusions reached in order to present a chronological sequence of events that eventually formed the present landscape.

PHASE I. THE AREA PRIOR TO GLACIATION

Prior to glaciation there was an upper Cretaceous bedrock high consisting predominantly of marine shales and sandstones gently dipping to the south-west. This subsequently served as the nucleus over and around which two phases of a Laurentide ice sheet stagnated.

PHASE II. THE FIRST ICE SHEET ADVANCE

The first encroachment of ice was responsible for the deposition of the lower till. Ice movement was from the north-east.

Field evidence does not offer any insight into reconstructing the topography and drainage regime of the first stade. However subsequent to the disappearance of the

first ice mass, weathering of the top horizons in the lower till resulted in a pink horizon which was overridden, incorporated and secondarily deposited within the upper till unit by the second ice sheet advance.

PHASE III. THE SECOND ICE SHEET ADVANCE

After a time interval of unknown duration, a second ice sheet advanced into east-central Alberta and, like the first, completely engulfed and overrode the upper Cretaceous bedrock high upon which the preceding ice sheet had stagnated and deposited the lower till. Similar lithologies of the upper and lower tills again suggest a north-east source for this advance.

The advance of the second ice sheet marked the last phase of glaciation in central Alberta. It is known that a stagnating environment was present in the area as late as 9,050 years B.P. This is based on three radiometric dates obtained for freshwater mollusca collected from superglacial lacustrine sediments in the moraine.

Landforms which resulted from the stagnation of the ice sheet include prairie mounds, till ridges, kames, outwash fans, stream channels and kettles.

The drainage regime of the moraine during this time is discussed in Chapter 2.

PHASE IV. THE EARLY POSTGLACIAL

During early postglacial times the dominant summer

winds transported sands and silt from the Sturgeon-Redwater river dune field and the floor of Lake Edmonton and deposited them over the northern areas of the moraine where they were interstratified and mixed with meltwater sands.

CHAPTER 8

CHRONOLOGY OF EVENTS

An absolute chronology of events during the development of the Cooking Lake moraine is difficult to determine accurately. This is due to the scarcity of datable material in both till units and in the superglacial lacustrine material which overlies the upper till.

Chronology of the Lower Till

Wood has been found above the lower till unit in the Fort Assiniboine area, approximately 75 miles north-west of Edmonton, and radiocarbon dated at 52,200 ± 1760 years B.P. (St. Onge, 1969; Lowdon et al, 1971). It is assumed that the lower till at this locality is the same as the lower till of the Cooking Lake moraine and that the glacial advance depositing the till was of early Wisconsin age.

No datable material has yet been found in either till unit of the moraine.

Chronology of the Upper Till and Superglacial Lacustrine Sediments

Three radiocarbon dates have been obtained in the moraine for molluscan shell material taken from superglacial lacustrine sediments which overlie the upper till. These dates are 10,900±190; 10,880±155 and 9,050±150 years B.P. and are documented in Appendix 8.

The second ice advance into the area was therefore between 11,000 and 51,000 years ago, making it mid to late Wisconsin in age. No datable material has yet been found in the upper till.

From the above dates it appears that the ice of the second advance stagnated in the area for approximately 2,000 years before it and the superglacial lakes disappeared.

Discussion

The calcium content of the upper till in the moraine is high with respect to most other cations present. It is therefore assumed that the water of the superglacial lakes was also calcium rich; a factor which could have caused an excess carbonate build-up in shells living at the time. This constitutes a source of error for the C14 dates obtained and suggests that the dates may be maximum.

CHAPTER 9

PROPOSALS FOR FURTHER INVESTIGATION

Mapping of the Cooking Lake moraine during this study has drawn attention to several problems and anomalies which may be resolved through further research. The objectives pertaining to these additional studies are defined as follows:

1. A more comprehensive understanding of the synglacial drainage patterns over the moraine may be obtained by accurately determining the highest shorelines of all major lakes in the area. Such shorelines arose when lake levels were at their highest and hence at a time when the development of the present day drainage was probably in its initial stages. Such shorelines are not always discernable on aerial photographs and so field study is necessary. The results of such a survey may lead to the inferred join-up of many lakes otherwise considered separate since their formation in late glacial-early post-glacial time. The deduction of the two lake systems described in Chapter 2 is based on field evidence of this type.

2. Further drilling of the bedrock high just north of Cooking Lake (Plate 1) will prove whether the bedrock is a constituent part of a very large erratic englacially or superglacially rafted into the area from the Grand Rapids Formation of the Fort McMurray region, or whether it is

simply a bedrock high of in situ Edmonton Formation. The position of the high is certainly very close to the position of the Cooking Lake divide which itself is a function of the bedrock topography.

3. To determine an accurate chronology for geologically significant events in the area, radiometrically datable organic material must be found, preferably between the two till units so that there is some degree of time control for delineating ice sheet advance into central Alberta.

More organic material from superglacial lacustrine sediments and fluvioglacial outwash will provide time markers for the advanced stages of ice break-up in the area.

4. Except for a study carried out by F. W. Schwartz (University of Alberta, unpublished) in the Hastings Lake vicinity, little data has so far been amassed pertaining to the overall groundwater geochemistry and flow regimes of the moraine.

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APPENDIX 1
ANALYTICAL DATA OF THE TILLS

Section Number	Sample Number	Lower/ Upper Till	Colour	Texture: Sand	Silt	Clay	Lithology: Σ	Locals	Acids	Basics	Carbs.	Qtz*	Carbonates: Dolo.	Calcite	Total	Clay Mineralogy: Mont.	Ill.	Kaol.	Chlor.
175	1	lower	5Y 4.5/1	36.5	34.0	28.0	200	7.0	57.5	6.0	1.0	25.0	6.9	0.4	7.3	--	--	--	-
	2	lower	5Y 4.5/1	32.6	35.0	31.0	200	15.5	45.0	3.0	6.5	31.0	4.6	0.8	5.4	--	--	--	-
	3	lower	5Y 4.5/1	33.6	35.0	30.0	200	11.5	49.0	4.5	5.0	30.0	4.9	1.0	5.9	35	45	20	0
475	1	lower	5Y 4/1.5	30.6	39.0	27.0	200	20.5	39.0	4.0	6.5	27.5	4.6	0.0	4.6	30	50	20	0
	2	lower	5Y 4/1	40.2	36.0	22.0	200	20.5	32.0	4.0	7.5	36.0	3.6	0.2	3.8	--	--	--	-
	3	lower	5Y 4.5/1.5	32.7	34.0	32.0	200	23.5	38.5	3.5	5.0	29.5	4.8	0.6	5.4	35	45	20	0
675	1	lower	5Y 5/1.5	50.9	31.0	17.0	200	11.0	54.5	7.0	6.5	30.0	9.1	1.8	10.9	10	60	30	0
	2	lower	5Y 5/1.5	58.5	27.0	14.0	200	24.5	37.5	2.0	13.5	21.0	3.6	0.0	3.6	--	--	--	-
	3	lower	5Y 5/1.5	33.9	36.0	29.0	178	23.0	39.9	2.3	6.2	28.1	4.9	0.2	5.1	35	40	20	5
775	1	upper	2.5Y 5/3	37.8	36.0	25.0	200	8.5	47.0	2.5	5.0	37.0	4.6	0.4	5.0	35	45	20	0
	2	upper	2.5Y 5/2	32.2	41.0	26.0	118	9.3	32.2	3.4	6.8	48.3	4.4	0.2	4.6	--	--	--	-
	3	upper	2.5Y 5/3	35.8	34.0	29.0	200	7.0	52.0	4.0	8.5	28.0	5.2	0.5	5.7	30	55	15	0
	4	upper	2.5Y 5/3	35.2	36.0	28.0	200	15.0	45.5	3.0	7.0	30.5	4.6	1.2	5.8	--	--	--	-
12375	0	lower	2.5Y 5/3	30.4	35.0	32.0	200	28.0	15.0	3.0	31.5	22.0	7.4	3.4	10.8	10	60	20	10
	1	lower	2.5Y 5/3	44.0†	34.0	22.0	70	20.0	50.0	0.0	22.9	----	6.3	3.0	9.3	--	--	--	-
	2	lower	2.5Y 3.5/2	36.0†	30.0	34.0	100	10.0	69.0	3.0	15.0	----	4.9	2.8	7.7	10	30	60	0
	3	upper	2.5Y 4.5/4	47.0†	31.0	22.0	100	13.0	77.0	1.0	6.0	----	5.1	0.0	5.1	--	--	--	-
	4	upper	2.5Y 5.5/3	47.0†	28.0	25.0	100	9.0	79.0	2.0	8.0	----	4.1	0.8	4.9	--	--	--	-
	5	upper	2.5Y 5.5/3	49.0†	29.0	22.0	100	8.0	85.0	1.0	5.0	----	5.1	0.8	5.9	30	55	15	0
14775	1	lower	2.5Y 6/4	33.5	35.0	30.0	200	19.5	31.5	3.0	2.5	44.0	3.8	0.4	4.2	--	--	--	-
	2	upper	2.5Y 5.5/3	33.0	36.0	30.0	200	10.0	41.0	5.5	8.0	36.0	4.4	0.4	4.8	--	--	--	-
	3	upper	2.5Y 5/3	35.9	34.0	29.0	200	10.5	50.5	6.5	5.5	27.5	3.5	1.3	4.8	50	40	10	-
	4	upper	2.5Y 5/3	33.7	35.0	30.0	194	10.3	43.8	3.1	3.6	37.1	2.9	0.8	3.7	--	--	--	-
16575	1	lower	2.5Y 6/3	39.5	33.0	26.0	200	8.0	42.5	1.5	0.5	47.0	4.2	0.4	9.6	30	55	20	0
	2	upper	2.5Y 6/3	34.8	38.0	26.0	200	8.0	48.0	4.0	8.5	31.0	3.4	0.6	4.0	--	--	--	-
	3	upper	2.5Y 6/3	43.4	35.0	20.0	200	11.0	41.5	4.0	10.0	32.5	3.8	0.8	4.6	45	40	15	0
	4	upper	2.5Y 6/3	39.8	40.0	19.0	200	7.0	46.0	5.0	5.0	37.0	4.3	0.8	5.1	--	--	--	-
17375	1	upper	2.5Y 6/3	60.0	23.0	16.0	200	9.0	38.5	6.5	12.0	26.0	7.4	2.0	9.4	15	65	20	0
	2	upper	2.5Y 6/3	53.0	28.0	18.0	200	12.5	41.0	8.5	10.5	27.0	8.9	1.0	9.9	--	--	--	-
	3	upper	2.5Y 5/3	50.4	30.0	18.0	200	11.5	46.5	8.0	13.0	20.5	9.4	2.1	11.5	5	75	20	0
	4	upper	2.5Y 5/3	53.8	29.0	16.0	200	3.0	49.5	8.5	11.0	28.5	8.3	2.9	11.2	--	--	--	-
18075	1	upper	2.5Y 6/3	43.4	37.0	18.0	200	4.5	40.0	3.0	2.0	49.0	5.3	0.3	5.6	35	50	10	10
	2	upper	2.5Y 6/3	43.2	37.0	18.0	200	9.0	49.0	5.0	5.0	31.5	5.0	1.1	6.1	--	--	--	-
	3	upper	2.5Y 6/3	41.7	39.0	18.0	200	6.0	53.5	5.5	12.5	22.0	6.1	0.0	6.1	--	--	--	-
	4	upper	2.5Y 6/3	42.6	36.0	20.0	200	8.5	40.0	6.0	11.5	33.5	4.6	2.0	6.6	45	40	15	0
19775	1	upper	2.5Y 6/3	32.4	33.0	33.0	215	7.9	43.7	1.9	1.9	44.7	5.3	0.8	6.1	35	45	20	0
	2	upper	2.5Y 5/3	35.3	33.0	30.0	200	11.5	50.5	3.0	4.0	31.0	5.5	1.6	7.1	--	--	--	-
	3	upper	2.5Y 5/3	34.7	33.0	30.0	200	8.0	44.5	6.5	5.0	36.5	5.7	0.4	6.1	35	45	20	0
19875	1	upper	2.5Y 6/3	25.3	46.0	28.0	200	12.0	36.5	2.0	2.5	49.0	4.4	0.0	4.4	--	--	--	-
	2	upper	2.5Y 6/3	40.5	34.0	24.0	200	12.0	47.5	12.5	4.5	23.5	4.6	0.0	4.6	30	50	20	0
	3	upper	2.5Y 6/3	42.7	33.0	23.0	200	11.5	48.5	5.0	5.0	29.5	5.1	0.6	5.7	--	--	--	-
	4	upper	2.5Y 6/3	41.9	35.0	22.0	200	10.0	43.5	6.5	15.5	26.0	4.9	0.4	5.3	30	50	20	0
19975	1	upper	2.5Y 5/3	40.7	29.0	29.0	200	4.0	41.5	2.0	1.5	51.0	4.4	3.4	7.8	30	50	20	0
	2	upper	2.5Y 5/3	41.7	32.0	25.0	200	11.5	46.0	6.5	3.0	33.0	4.6	0.8	5.4	--	--	--	-
	3	upper	2.5Y 5/3	39.2	33.0	26.0	200	4.0	62.0	7.5	3.5	23.0	4.7	0.8	5.5	--	--	--	-
	4	upper	2.5Y 5/3	40.2	33.0	26.0	200	12.0	44.0	11.5	7.5	25.5	4.8	3.4	8.2	30	55	15	0
20075	1	upper	2.5Y 5/2	37.0	32.0	30.0	200	14.0	27.5	3.5	7.5	47.0	3.8	0.4	4.2	--	--	--	-
	2	upper	2.5Y 5/2	36.0	33.0	30.0	200	20.5	41.0	7.5	6.0	24.5	3.4	0.8	4.2	--	--	--	-
	3	upper	2.5Y 5/2	32.9	35.0	31.0	200	13.0	36.5	12.0	5.0	33.5	4.6	3.2	7.8	50	35	15	0
	4	upper	2.5Y 5/2	33.8	37.0	28.0	200	14.5	45.0	4.0	8.0	29.0	4.7	2.6	7.3	35	45	15	0
20175	1	upper	2.5Y 5/3	36.6	31.0	31.0	200	6.0	40.0	4.0	7.5	42.5	4.5	0.1	4.6	--	--	--	-
	2	upper	2.5Y 6/3	34.8	34.0	30.0	200	8.0	53.0	6.0	4.0	29.0	4.9	0.4	5.3	30	50	20	5
	3	upper	2.5Y 5/3	36.6	33.0	29.0	200	13.0	59.5	4.5	3.5	20.0	3.7	0.0	3.7	--	--	--	-
	4	upper	2.5Y 5/3	35.5	33.0	30.0	200	9.0	68.0	5.5	1.0	18.0	2.5	0.2	2.7	--	--	--	-
20275	1	upper	2.5Y 5/3	44.9	31.0	22.0	200	6.0	42.0	4.0	6.5	44.0	5.3	0.0	5.3	25	55	20	0
	2	upper	2.5Y 4/2	36.2	34.0	29.0	200	14.5	44.0	9.0	7.0	25.0	4.9	0.4	5.3	30	50	20	0
	3	upper	2.5Y 4/3	48.6	30.0	19.0	200	8.5	48.5	10.5	5.0	27.5	5.7	0.4	6.1	30	50	20	0
	4	upper	2.5Y 5/2	31.9	35.0	32.0	200	8.0	49.0	7.0	6.5	29.0	5.3	1.2	6.5	30	45	20	0
20375	1	upper	2.5Y 4/3	39.5	33.0	26.0	200	11.0	27.5	2.5	9.0	50.0	5.5	0.3	5.8	20	55	20	5
	2	upper	2.5Y 5/2	37.7	33.0	28.0	200	11.0	43.5	7.0	9.0	29.0	3.8	0.8	4.6	--	--	--	-
	3	upper	2.5Y 5/2	36.8	34.0	28.0	200	15.0	40.5	5.0	7.0	33.0	4.2	1.[illegible]	6.0	--	--	--	-
	4	upper	2.5Y 5/2	36.8	32.0	30.0	200	13.5	40.5	9.5	10.0	26.0	3.7	2.2	5.9	--	--	--	-

* undifferentiated grains

† sand and coarser

APPENDIX 2

Cobble Lithology (10-15 cms)

Sample Locality Number	Σ	% Acid Ign	% Acid Met	% Basic Ign	% Basic Met	% Tertiary Quartzite	% Athabasca Sandstone	% Locals	% Carbs
2275	105	15.2	9.5	1.9	1.9	24.8	46.7	0.0	0.0
6275	100	12.0	13.0	1.0	3.0	26.0	41.0	4.0	0.0
7875	112	7.1	31.3	1.8	11.6	11.6	28.6	8.0	0.0
8875	102	10.8	15.7	2.0	6.9	17.7	44.1	2.0	1.0
10775	95	23.2	6.3	2.1	2.1	30.5	34.7	0.0	1.1
13975	104	15.4	7.7	1.0	2.9	26.9	33.7	9.6	2.9
14475	102	27.5	12.8	2.9	3.9	24.5	27.5	0.0	1.0
14675	103	23.3	14.6	2.9	2.9	18.5	35.0	1.0	1.9
15675	101	26.7	11.9	2.0	3.0	20.8	34.7	1.0	0.0
17675	101	10.9	7.9	3.0	8.9	9.9	44.6	5.9	8.9
18975	106	13.2	12.3	0.9	6.6	21.7	44.3	0.9	0.0

APPENDIX 3

The Major, Minor and Trace Element Mineralogy* of the Tills

Till Unit	Major and Minor Element					Trace Elements				
	K	Ca	Ti	Mn	Fe	Cu	Zn	Rb+	Sr+	Zr+
Ablation (lower)	337	935	508	275	18,142	126	242	2104	3876	8384
Ablation (upper)	330	852	499	278	18,030	130	247	2023†	4122†	8538
Pink Unit	436	1406	457	322	19,919	119	183	2130†	4092†	7690

*The data represent the mean values of counts per 30 seconds for each of the till units (79 till samples were analyzed).

+Values exaggerated due to the positions of these elements close to the end of the molybdenum tube analyzing spectrum.

†The mean quantitative values for Rb and Sr content in the upper ablation till unit are ∿76 ± 10 p.p.m. and ∿165 ± 20 p.p.m. respectively, and in the pink unit horizon ∿181 ± 10 p.p.m. and ∿181 ± 20 p.p.m. respectively.

APPENDIX 4

Analytical data of the Pink Unit

	Sample Locality No.				
	P-5675	P-10575	P-12475	P-16175	P-17575
Colour	10R 6/3	2.5Y 4.5/4	10R 5.5/4	10R 6/3	10R 6/3
Texture					
% Sand	47.0	41.0	46.0	42.0	44.0
% Silt	33.0	35.0	38.0	35.0	33.0
% Clay	20.0	24.0	16.0	23.0	23.0
Lithology (1-2 mm)					
Σ	200	200	200	200	200
% Locals	0.0	0.0	5.0	2.5	3.5
% Acids	79.5	65.5	42.0	54.5	66.0
% Basics	7.0	22.5	9.0	10.0	13.0
% Carbs.	2.0	2.0	27.0	18.5	2.0
% Qtz.	11.0	10.0	15.0	14.0	15.5
Lithology (2-4 mm)					
% Igneous	60.5	60.0	48.0	64.0	67.0
% Meta.	34.5	31.0	24.0	20.0	27.0
% Locals	3.5	9.0	16.0	4.0	5.0
% Carbs.	1.5	0.0	12.0	12.0	1.0
Carbonates					
% Dolo.	3.3	1.3	7.1	4.9	3.4
% Calcite	3.6	0.0	12.2	0.1	0.6
% Total	6.9	1.3	19.3	5.0	4.0
Clay Mineralogy					
% Mont.	5	5	--	0	20
% Ill.	70	75	--	75	55
% Kaol.	20	20	--	20	25
% Chlor.	10	0	--	5	0

APPENDIX 5

Prairie mound density distribution between 53° 12' 22' and 53° 42' 8' N; 112° 37' 58' and 113° 16' 43" W

-	-	-	-	-	-	-	-	-	-	-	30	75	33	29	45	73	-	57	50	55	45	60	50	54	71	48
-	-	-	-	-	-	-	-	-	-	-	45	69	100	75	46	85	-	-	45	52	74	82	28	65	112	10
-	-	-	-	-	-	70	45	56	62	127	215	110	80	59	60	50	-	-	40	45	50	52	52	25	45	45
-	-	-	-	25	40	35	43	61	74	145	175	88	74	58	75	12	30	32	45	35	80	45	48	48	45	38
-	-	-	-	58	26	28	70	35	40	65	120	40	56	73	-	15	31	30	25	30	110	82	80	43	58	45
-	95	63	75	43	25	51	48	65	60	50	38	52	-	80	-	34	60	44	30	73	90	80	80	85	75	130
-	56	57	16	14	25	88	83	85	50	110	80	52	54	49	82	-	-	120	100	50	116	140	100	130	137	122
-	45	50	20	70	42	53	10	61	80	60	79	85	30	45	30	-	-	50	84	100	80	65	90	110	100	95
-	69	55	49	25	70	116	88	85	80	75	50	75	25	26	23	-	45	120	85	118	60	111	95	130	80	90
-	50	25	35	25	40	87	65	53	84	50	40	65	63	100	72	75	78	100	22	65	70	40	97	76	80	110
-	30	38	0	15	25	40	49	68	39	32	30	28	40	50	60	50	70	36	65	55	82	107	69	70	81	100
-	50	41	39	26	31	30	15	5	4	27	26	30	87	22	64	35	68	95	80	45	90	70	55	80	107	100
-	75	46	17	48	56	40	34	2	22	50	28	47	50	110	73	55	67	40	69	65	75	100	100	45	52	55
-	69	50	16	6	63	15	31	6	13	40	15	-	45	110	72	60	92	76	40	70	38	87	120	62	83	35
-	100	118	-	-	51	60	45	75	30	60	17	-	28	75	76	90	63	72	60	55	76	126	52	90	40	45
-	100	170	145	66	-	30	50	21	68	40	32	38	27	31	-	30	10	20	60	70	80	58	44	48	53	-
-	46	93	174	98	72	75	79	27	6	40	42	-	-	25	-	35	33	21	25	90	160	20	58	79	92	-
-	123	85	88	125	113	52	79	42	-	-	-	-	7	20	30	10	49	55	24	57	115	103	90	55	53	-
-	70	77	56	60	79	42	-	-	-	-	-	-	-	24	40	-	-	32	32	67	77	70	70	90	45	-
-	66	31	94	75	90	21	-	-	-	-	-	-	26	-	-	-	32	42	15	67	80	102	86	94	52	-
-	28	31	31	32	-	-	-	-	-	-	10	70	41	-	60	53	25	12	25	100	200	120	106	89	34	-
-	65	50	34	70	109	96	91	92	56	97	75	80	93	92	73	51	68	77	36	148	68	45	20	90	10	-
-	50	33	40	65	50	37	55	30	55	60	45	94	80	90	61	67	76	89	148	148	40	36	41	62	1	-
65	40	45	-	16	12	50	48	50	32	-	-	-	86	80	40	71	68	71	82	58	10	42	76	65	9	-
43	36	45	41	12	25	57	32	13	-	-	-	76	79	70	23	46	30	63	93	50	82	76	80	43	19	-
70	62	50	-	58	-	-	30	17	-	-	-	72	76	80	-	25	60	110	77	42	90	85	35	6	46	-
80	67	97	55	65	-	-	35	39	36	105	67	70	70	70	64	55	73	145	85	70	69	60	65	59	31	-
76	81	88	38	70	30	67	65	-	-	-	-	59	59	56	70	86	60	66	85	48	80	135	67	34	50	-
55	54	51	45	48	17	60	57	-	-	-	-	50	56	30	92	75	40	114	80	79	82	82	50	33	105	-
110	49	62	36	51	23	42	75	24	16	34	68	90	113	90	-	-	63	60	160	110	80	145	66	92	-	-
102	75	60	50	55	61	45	78	40	40	92	137	200	-	-	-	-	39	72	110	65	78	135	65	24	-	-
113	80	50	113	93	50	85	83	26	15	30	70	132	56	65	-	-	-	-	70	-	-	-	-	-	-	-
110	50	95	60	65	44	65	34	18	21	30	80	115	36	98	87	93	45	-	70	-	-	-	-	-	-	-
85	82	150	48	65	55	110	103	75	6	1	50	60	39	80	86	110	95	-	-	-	-	-	-	-	-	-

APPENDIX 6

Surificial drift relief between 53° 12' 22" and 53° 42' 8" N;
112° 37' 58" and 113° 16' 43" W

-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	1	1	1	1	1	1	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	1	1	1	1	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	1	1	1	1	1	2	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	1	1	1	1	2	2	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	1	1	-	1	1	1	1	2	2	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	1	1	1	1	1	1	2	1	1	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	1	2	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	1	1	1	1	1	1	1	1	1	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	1	1
-	1	2	1	1	1	1	1	1	1	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	1	1
-	1	2	2	1	1	1	1	2	1	1	1	-	1	1	-	-	1	-	-	-	-	2	-	-	-	-
-	1	2	2	2	2	1	1	1	1	1	1	-	1	1	-	-	-	-	-	-	-	-	1	-	-	1
-	1	1	1	2	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	2	1	-	1	-	-
-	2	2	2	2	1	2	1	1	-	-	-	-	-	1	-	1	2	-	-	-	-	-	-	1	-	1
-	1	1	1	1	1	1	-	-	-	-	1	1	1	-	-	-	-	1	1	1	-	-	-	2	1	-
-	1	1	1	1	2	2	1	1	1	1	1	-	-	-	-	-	1	-	-	2	-	-	2	-	-	1
-	1	2	1	1	2	2	2	1	2	1	1	-	3	-	1	-	-	-	-	-	-	-	-	-	1	-
-	2	2	2	1	1	2	2	2	2	2	1	-	-	-	2	2	-	1	1	1	-	-	1	-	1	-
-	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	1	-	-	-	1	-	-	-	-	-
-	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-
-	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	1	-	1	-	-	-	-	-	-
-	1	1	1	1	1	1	1	1	1	1	1	-	-	-	2	-	-	-	-	-	1	1	-	-	-	1
-	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	2	1	1	1	1	-	-	1	1
-	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	1	1	1	1	1	1	1	1	1	1	1	-	-	-	-	-	-	1	-	-	-	1	-	-	-	-
-	-	-	-	1	-	1	-	1	-	1	-	-	-	1	-	1	-	-	-	-	-	-	-	-	-	-
-	-	-	-	1	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
-	-	1	1	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

APPENDIX 7

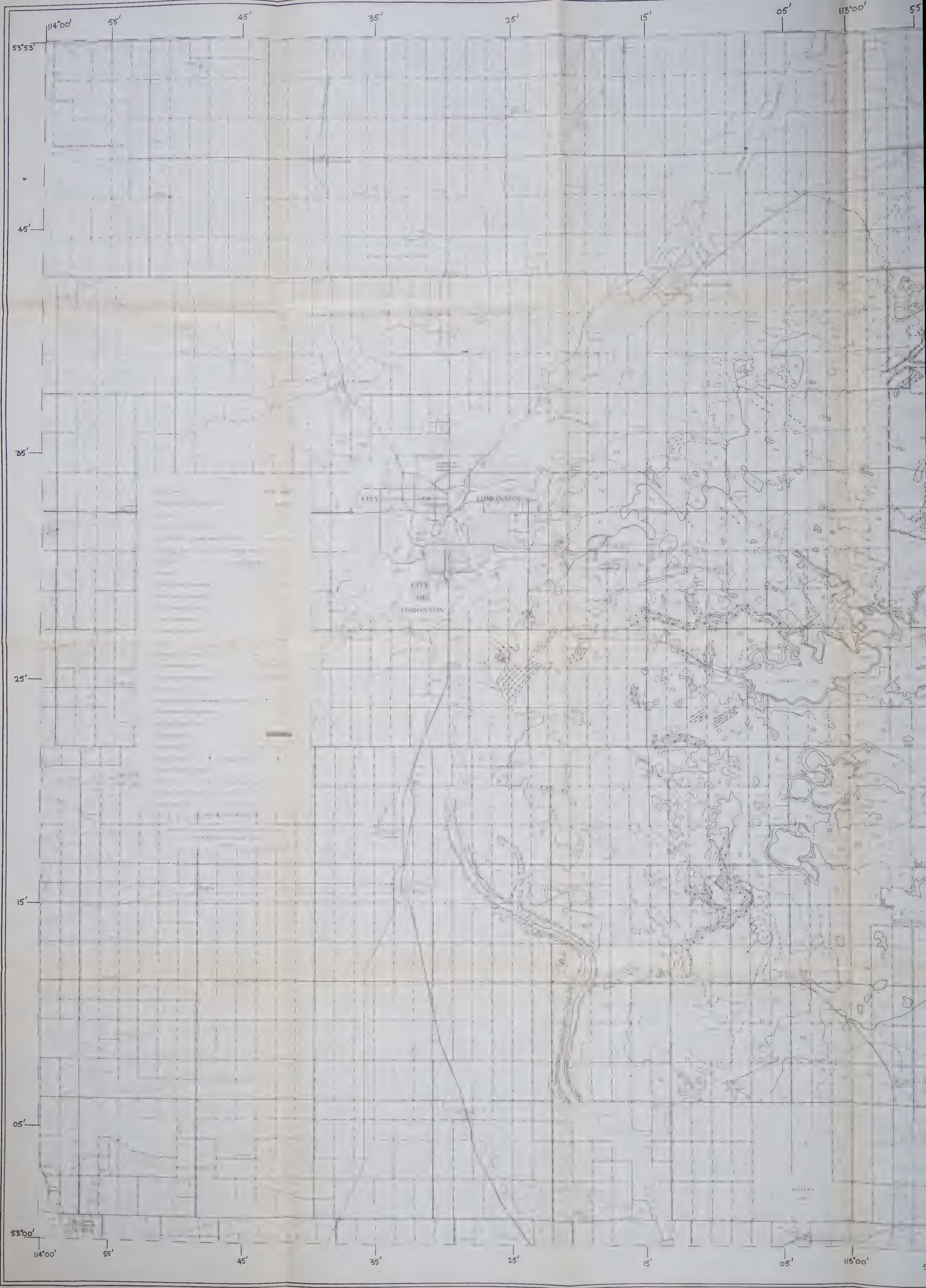
Bedrock elevation between 53° 12' 22" and 53° 42' 8" N; 112° 37' 58" and 113° 16' 43" W

1900	1930	1950	1955	1970	2000	2037	2050	2113	2150	2150	2130	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1915	1955	1955	1968	2025	2029	2020	2100	2150	2179	2156	2200	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1920	1955	1968	1987	2049	2043	2030	2110	2150	2190	2200	2195	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1950	1987	2000	2052	2050	2075	2110	2100	2140	2200	2250	2275	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1950	2000	2050	2070	2090	2100	2175	2150	2145	2175	2215	2245	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1990	2050	2050	2075	2130	2150	2215	2245	2225	2185	2185	2220	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2020	2075	2060	2060	2190	2170	2230	2290	2280	2250	2180	2220	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2050	2075	2115	2150	2175	2150	2220	2300	2355	2300	2215	2210	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2095	2100	2175	2200	2235	2175	2200	2275	2350	2360	2320	2220	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2175	2200	2160	2180	2250	2200	2180	2250	2300	2375	2370	2310	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2250	2255	2245	2225	2250	2260	2200	2250	2315	2375	2380	2375	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2300	2325	2275	2290	2285	2280	2260	2265	2325	2380	2425	2435	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2330	2330	2280	2250	2315	2315	2350	2275	2300	2350	2400	2435	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2387	2380	2325	2360	2325	2360	2410	2300	2350	2350	2425	2425	-	2470	-	2400	-	-	-	-	-	-	-	2305	2290	2256	2200
2400	2375	2330	2300	2350	2380	2410	2400	2385	2375	2400	2400	-	2420	-	-	-	2400	-	-	2330	-	-	-	-	2290	2200
2350	2385	2375	2375	2345	2375	2375	2430	2430	2375	2375	2370	-	2400	2430	-	-	2450	-	-	-	-	2220	-	-	-	-
2300	2375	2390	2415	2375	2360	2450	2420	2385	2375	2400	2400	-	2311	2405	-	-	-	-	-	-	-	-	2210	-	-	2231
2350	2375	2375	2435	2450	2425	2415	2415	2400	2358	2325	2325	-	-	2395	2400	-	2365	-	2312	2330	2287	2273	-	2195	-	-
2362	2415	2450	2420	2460	2435	2430	2338	2335	2300	2300	2300	-	-	2370	2370	2300	2255	-	-	-	-	-	-	2200	-	2140
2405	2430	2470	2475	2480	2425	2400	2330	2300	2300	2300	2342	2227	2210	-	-	-	-	2250	2277	2255	-	-	-	2215	2140	-
2426	2470	2450	2470	2430	2400	2390	2375	2383	2367	2363	2385	-	-	-	-	-	2351	-	-	2210	-	-	2160	-	-	2205
2375	2430	2450	2470	2480	2420	2450	2385	2425	2425	2425	2400	-	2340	-	2360	-	-	-	-	-	-	-	-	-	2218	-
2400	2412	2430	2455	2455	2475	2580	2455	2465	2475	2425	2425	-	-	-	2421	2360	-	2387	2400	2340	-	-	2235	-	2270	-
2430	2435	2425	2426	2425	2450	2480	2510	2510	2475	2450	2450	-	-	-	-	-	2363	-	-	-	2286	-	-	-	-	-
2430	2435	2445	2450	2465	2475	2520	2510	2475	2450	2425	2425	-	-	-	-	-	-	-	-	-	-	-	-	2330	-	-
2390	2400	2430	2440	2456	2465	2485	2480	2470	2450	2450	2450	-	-	-	-	-	-	2375	-	2240	-	-	-	-	-	-
2385	2405	2420	2425	2425	2470	2460	2515	2500	2485	2480	2475	-	-	-	2375	-	-	-	-	-	2347	2375	-	-	-	2300
2380	2415	2430	2450	2465	2480	2530	2530	2450	2450	2450	2450	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2365	2400	2430	2445	2450	2505	2525	2530	2450	2425	2450	2450	-	-	-	-	-	-	2418	2435	2470	2418	2425	-	-	2260	2250
2400	2400	2430	2450	2450	2475	2485	2537	2525	2470	2500	2500	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2430	2430	2425	2475	2490	2487	2482	2500	2525	2535	2515	2530	-	-	-	-	-	-	2415	-	-	-	2400	-	-	-	-
-	-	-	-	2505	-	2520	-	2465	-	2490	-	-	-	2515	-	2445	-	-	-	-	-	-	-	-	-	-
-	-	-	-	2480	2520	2515	-	-	-	-	-	-	-	-	2600	-	-	-	-	-	-	-	-	-	-	-
-	-	2470	2410	2480	-	2530	2490	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

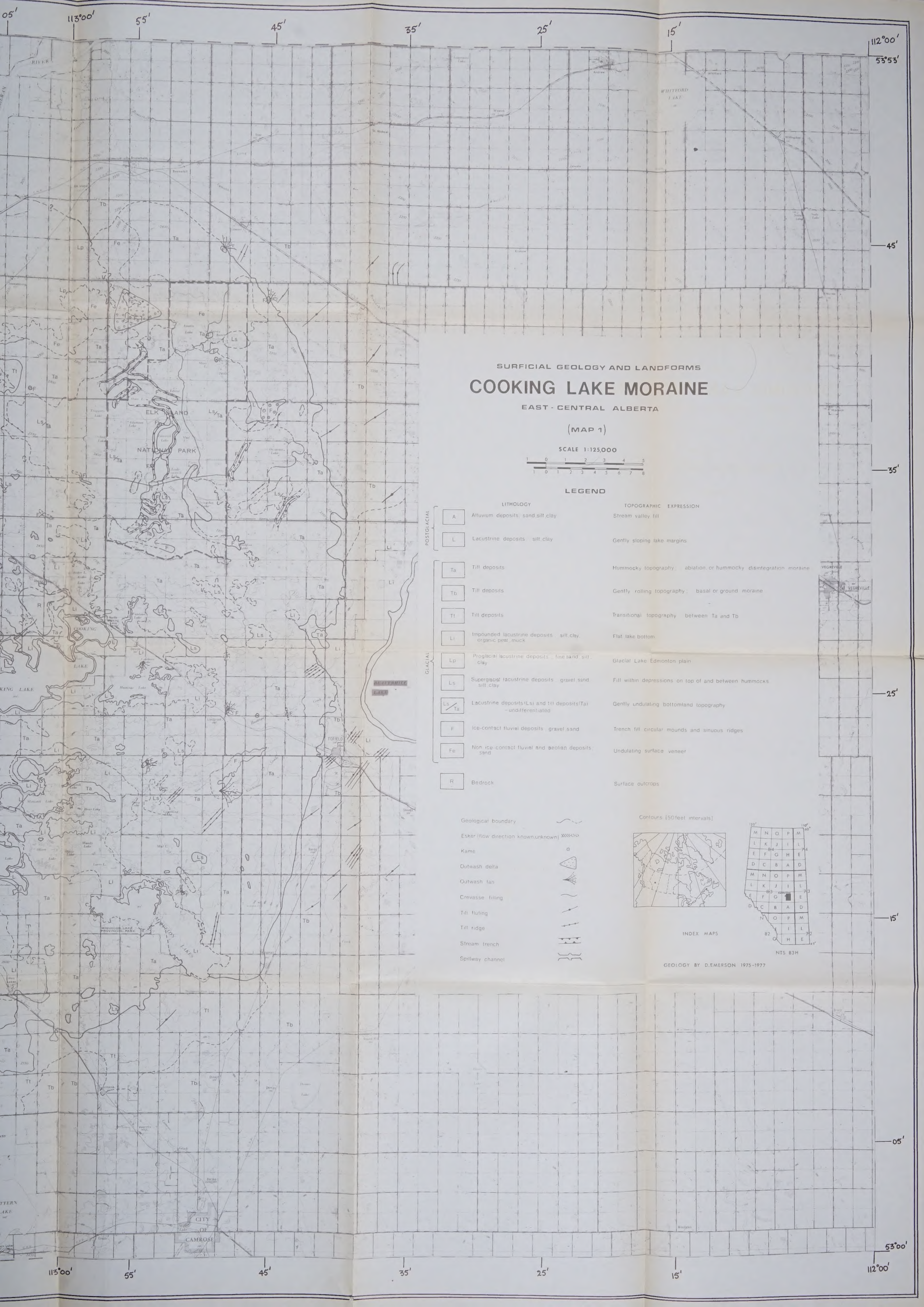
APPENDIX 8

RADIOCARBON DATE DOCUMENTATION

Laboratory Dating Number	Date (Years B.P.)	Location		Collector	Material	Comments
		Lat. N.	Long. W.			
GSC-1019-2	52,200±1760	54° 21' 30"	114" 53' 00"	D. A. St. Onge	Wood	Taken from outwash gravel above till. If finite date is valid, it <u>may</u> date stratified intertill deposit in area (St. Onge, 1969).
GSC-2404	10,900±190	53° 31' 00"	113° 00' 00"	D. Emerson	Shell	Shells of fresh-water mollusca, found in super-glacial lacustrine sediments
I-8484	10,880±155	53° 32' 50"	113° 02' 50"	J. A. Westgate and D. Emerson	Shell	Shells of fresh-water mollusca
I-4552	9,050±150	53° 35' 15"	113° 04' 25"	J. A. Westgate and D. Emerson	Shell	Shells of fresh-water mollusca found in super-glacial lacustrine pockets.



114°00'
55'
45'
35'
25'
15'
05'
113°00'
55'
53°53'
45'
35'
25'
15'
05'
53°00'
Alexander Indian Reserve No. 134
ST. ALBERT
CITY OF EDMONTON
CITY OF EDMONTON



SURFICIAL GEOLOGY AND LANDFORMS
COOKING LAKE MORAINE
EAST - CENTRAL ALBERTA
(MAP 1)
SCALE 1:125,000
LEGEND
LITHOLOGY
TOPOGRAPHIC EXPRESSION
POSTGLACIAL
A Alluvium deposits sand silt clay
Stream valley fill
L Lacustrine deposits silt clay
Gently sloping lake margins
GLACIAL
Ta Till deposits
Hummocky topography ablation or hummocky disintegration moraine
Tb Till deposits
Gently rolling topography basal or ground moraine
Tt Till deposits
Transitional topography between Ta and Tb
Li Impounded lacustrine deposits silt clay organic peat muck
Flat lake bottom
Lp Proglacial lacustrine deposits fine sand silt clay
Glacial Lake Edmonton plain
Ls Supergiacial lacustrine deposits gravel sand silt clay
Fill within depressions on top of and between hummocks
Ls/Ta Lacustrine deposits (Ls) and till deposits (Ta) - undifferentiated
Gently undulating bottomland topography
F Ice-contact fluvial deposits gravel sand
Trench fill circular mounds and sinuous ridges
Fe Non ice-contact fluvial and aeolian deposits sand
Undulating surface veneer
R Bedrock
Surface outcrops
Geological boundary
Esker (flow direction known,unknown)
Kame
Outwash delta
Outwash fan
Crevasse filling
Till fluting
Till ridge
Stream trench
Spillway channel
Contours (50feet intervals)
INDEX MAPS
NTS 83H
GEOLOGY BY D.EMERSON 1975-1977
ELK ISLAND NATIONAL PARK
COOKING LAKE
TOFIELD
VEGREVILLE
CITY OF CAMROSE
113°00'
112°00'
53°53'
53°00'

114°00'
55'
45'
35'
25'
15'
05'
113°00'
53°55'
45'
35'
25'
15'
05'
53°00'
Alexander Indian Reserve No. 134
MORINVILLE
NORTH SASKATCHEWAN RIVER
FORT SASKATCHEWAN
ST. ALBERT
BIG LAKE
EDMONTON INDUSTRIAL AIRPORT
CITY OF EDMONTON
COOKING LAKE
EDMONTON INTERNATIONAL AIRPORT
CALMAR
LEDUC
BIG HAY LAKE
COAL LAKE
BITTERN LAKE
Pigeon Lake Indian Reserve No. 138 A
REFERENCE
Built-Up Area and Corporate Boundary
Town — Village, Hamlet Locality
TOFIELD
Loome
Buildings
School, Church, Cemetery
Highway Paved
Gravelled
All Weather Road
Dry Weather Road
Truck Trail
Trails and Seismograph Lines (condition unknown)
Railways
Lake or Slough, Intermittent
Marsh, Swamp or Muskeg
Land Subject to Inundation
Stream, Intermittent
Irrigation Canal or Ditch
River
RAPIDS
SAND
DAM
FALLS
FERRY
Contours (50 Ft. Interval)
2850
2900
Prominent Mountain Peak
Township Boundary Surveyed
Unsurveyed
Section Line
National Park
Provincial Park
Rocky Mountains Forest Reserve
Oil or Gas Field
Indian Reserve
Historical Site
Fort Edmonton
Forestry Tower
Ranger Station
Gravel Pits, Mines, Quarries
Tank Farm
Tower
Campsite or Picnic Shelter
Wooded Area
Pipeline, Oil or Gas
Transmission Line
Contours from the Department of Mines and Technical Surveys
1:50000 National Topographic Series,
Ottawa


SYNGLACIAL DRAINAGE
COOKING LAKE MORAINE
EAST-CENTRAL ALBERTA
(MAP 2)
SCALE 1:125,000
LEGEND
Stream channel (defined undefined)
Channel outlet (defined)
Channel outlet (undefined)
Glacial lake margin
Pebble fabric in outwash
Preglacial drainage divide
ELK ISLAND
NATIONAL PARK
BEAVERHILL
LAKE
COOKING
LAKE
COOKING LAKE
MIQUELON LAKES
TOFIELD
VEGREVILLE
CITY
OF
CAMROSE
BITTERN
LAKE
WHITFORD
LAKE
113°00'
112°00'
53°53'
53°00'